

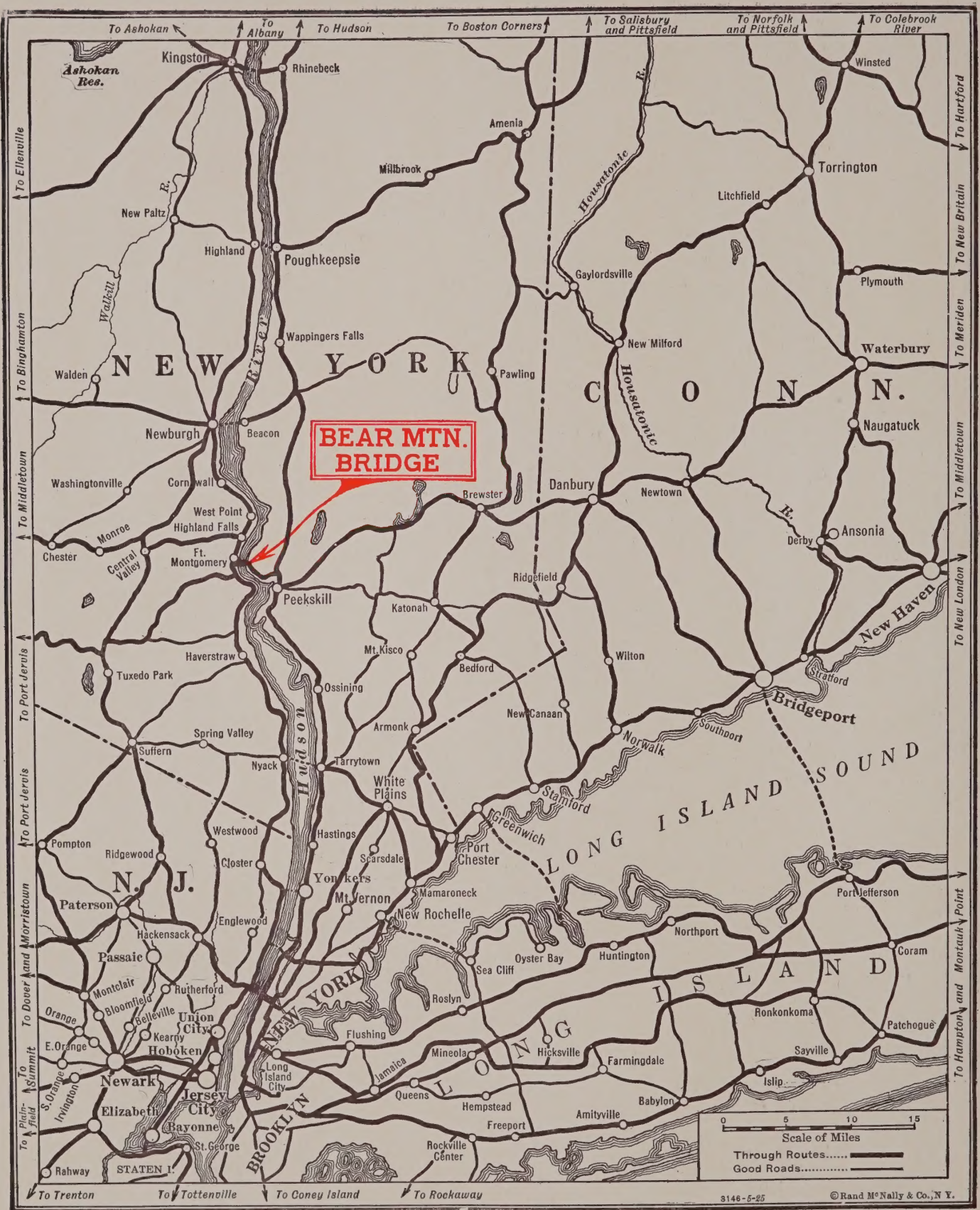
CONSTRUCTION OF
PARALLEL WIRE CABLES
FOR
SUSPENSION BRIDGES



John A. Roebling's Sons Company
Trenton, New Jersey.







**BEAR MTN.
BRIDGE**

Scale of Miles
Through Routes.....
Good Roads.....

Construction of

PARALLEL WIRE CABLES

for

SUSPENSION BRIDGES

*A photographic and textual
study of the fabrication of
Bridge Cables*

John A. Roebling's Sons Company
TRENTON, NEW JERSEY

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JOHN A. ROEBLING'S SONS COMPANY
TRENTON, NEW JERSEY

Construction of Parallel Wire Cables for Suspension Bridges.

DURING the last eighty years, the name of "Roebling" has been actively identified with suspension bridge design, materials and construction. Beginning with the building of the aqueduct across the Allegheny River at Pittsburgh in 1844, and continuing to the latest completed bridge of suspension type, namely, the Bear Mountain-Hudson River Bridge, this company has either furnished the fabricated cables or supplied the materials for cable fabrication and roadway suspension on practically every important bridge of this kind in the United States.

Among the larger structures, in addition to the Pittsburgh Aqueduct and the Bear Mountain-Hudson River Bridge mentioned above, with which the Roebling Company has been identified, are the Delaware Aqueduct, built in 1848; the Neversink Aqueduct, built in 1850; the Niagara Falls Bridge, across the rapids below Niagara Falls, built in 1854; the Allegheny Bridge at Pittsburgh, built in 1856; the Cincinnati-Covington Bridge completed in 1867; the Brooklyn Bridge, open to traffic in 1883; the Williamsburg Bridge in 1903; the Manhattan Bridge in 1909; and the Rondout Creek Bridge at Kingston, N. Y., completed in 1922.

The fact that to-day many of these bridges, after years of service, are handling modern traffic, under loads far beyond that originally contemplated, indicates the great foresight of the designers and the high quality of the materials entering into the structure.

The John A. Roebling's Sons Company, of Trenton, New Jersey, have been intimately associated with the construction of suspension bridges during the past three-quarters of a century. For this reason, from time to time, they have been asked how the large cables which form an important part of this type of bridge are fabricated and also the methods used in the suspension of the super-structure.

The Bear Mountain-Hudson River Bridge, which spans the Hudson River from Anthony's Nose on the east bank to Bear Mountain on the west bank, was opened for traffic November 26, 1924. All cable wire used in fabricating the two main cables, and the steel wire ropes used for foot bridges and suspenders, were furnished by the John A. Roebling's Sons Company.

During the erection of this bridge photographic studies were made at each step of construction, from the tower foundations to the completed bridge, and, in answer to the many questions which have been asked, the John A. Roebling's Sons Company has prepared this book, telling the story in pictorial form.

As a part of its large organization, the John A. Roebling's Sons Company maintains a highly trained engineering staff, which is always at the service of those having engineering problems in suspension bridge construction, as well as other problems involving use of wire and wire rope.

For convenience, the photographs have been arranged so that, with the text appearing under each picture, they tell the story of the construction of a modern suspension bridge. However, for those who are interested in the more technical phases of the subject, there follows a detailed and comprehensive study concerning the history of suspension bridge construction and the results of exhaustive tests, including charts, as to the physical properties of bridge cables and suspender ropes. Also the relative importance of secondary stresses.

PITTSBURGH AQUEDUCT

The John A. Roebling's Sons Company, through its founder, John A. Roebling, was the pioneer in the construction of parallel wire cables and long-span suspension bridges. The first great achievement along this line was in 1844, when the first suspension bridge or aqueduct supported by parallel wire cables, carrying the water and boats of the Pennsylvania Canal across the Allegheny River, at Pittsburgh, was constructed. This bridge consisted of seven individual spans, each 162 feet in length, supported by two cables seven inches in diameter. Each cable was composed of seven strands, made up of 236 wires 0.148 inches in diameter, totaling 1652 wires in each complete cable.

The success of this first suspension bridge was such that it was soon followed by others of greater capacity having longer spans and larger cables, the more important of which are briefly outlined as follows:

LACKAWAXEN AQUEDUCT

Built in 1848 in Pike County, Pennsylvania, spanning the Lackawaxen River about two miles from its mouth. It consisted of two 120 foot spans supported by two seven-inch diameter cables, each composed of seven strands made up of 236 wires 0.148 inches in diameter, totaling 1652 wires in each complete cable.

DELAWARE AQUEDUCT

Built in 1848 spanning the Delaware River at the mouth of the Lackawaxen River. It consisted of four 134 foot spans supported by two eight-inch diameter cables composed of seven strands, each containing 306 wires 0.148 inches in diameter, totaling 2142 wires in each complete cable.

HIGH FALLS AQUEDUCT

Built in 1848 spanning the Rondout Creek near High Falls, New York, consisting of a single 145 foot span, supported by two cables eight and one-half inches in diameter, composed of seven strands each containing 346 wires 0.148 inches in diameter, totaling 2422 wires in each complete cable.

RONDOUT AQUEDUCT

Built in 1850 spanning the Rondout Creek near its junction with the Hudson River, not far from Rondout, New York. It consisted of a single 170 foot span supported by two cables nine and one-half inches in diameter, each cable consisting of seven strands, composed of 432 wires 0.148 inches in diameter, totaling 3024 wires in each complete cable.

NEVERSINK AQUEDUCT

Built in 1850, spanning the Neversink Creek three miles above Port Jervis, having the same dimensions as the Rondout Aqueduct mentioned above.

NIAGARA FALLS BRIDGE

In 1854 there was accomplished the then thought impossible feat of constructing a combination railroad and highway suspension bridge across the Niagara Falls rapids. This bridge consisted of an 821-foot clear span between towers, supported from four cables ten inches in diameter, each cable consisting of seven strands, each strand composed of 520 wires 0.148 inches in diameter, making a total of 3640 wires in each cable.

ALLEGHENY BRIDGE

Built in 1856 across the Allegheny River, at Pittsburgh, having two spans of 344 feet each. This bridge was supported by four cables—two cables seven inches in diameter and two cables four inches in diameter, made up of wires 0.148 inches in diameter.

CINCINNATI BRIDGE

Opened to traffic January 1, 1867, crossing the Ohio River between Cincinnati, Ohio, and Covington, Kentucky. This bridge was another great undertaking of the Roebling Company. It has a clear span of 1057 feet, which was the longest in existence, at that time. It was supported by two cables, each having a diameter of twelve and one-third inches and composed of 19 strands, each strand containing 274 wires 0.148 inches in diameter, making a total of 5206 wires in each complete cable. The suspended length of each of these cables is 1700 feet between center line of anchorage pins. In 1896 and 1897, in order to accommodate greatly increased traffic conditions, this bridge was reinforced by two additional parallel wire cables, each ten inches in diameter and composed of seven strands of 520 wires 0.148 inches in diameter, totaling 3640 wires in each of the new cables. These cables were supported upon separate saddles directly over the old cables, and the proportionate loading was transferred to the new cables by means of special re-adjustment of the suspender ropes.

BROOKLYN BRIDGE

The completion of this famous structure, opened to traffic in 1883, marked the greatest advance in suspension bridge construction up to this time.

The bridge has a main span of 1595.5 feet, and is supported by four cables each having a diameter of fifteen and one-half inches. The cables consist of 19 strands, each composed of 282 steel wires 0.187 inches in diameter, after galvanizing, totaling 5358 wires in each cable.

The cables have an ultimate strength of approximately 11,200 tons each, and if the total amount of wire in all four cables was stretched in one continuous length, it would cover a distance of 14,568 miles.

The three most important differences between the Brooklyn Bridge and other suspension bridges built previously are:

1st—Great increase in cable length. Including both side spans this bridge has a total length of 3455.5 feet suspended from the cables. The total length of each of the cables between center lines of anchorage pins is 3578.5 feet, making them the longest parallel wire cables ever fabricated for a suspension bridge, even to the present day.

2nd—The Brooklyn Bridge marked the first use of steel as a material for bridge wire. All previous suspension bridge cables were fabricated from wire drawn from charcoal iron.

3rd—Prior to this time, cables were fabricated from bright wire and depended upon oil, grease, and paint for protection against the elements. In the Brooklyn Bridge, however, the cables were fabricated from galvanized wire, thus bringing into use for the first time, zinc as a protective coating for suspension bridge cable wire.

It was while locating one of the towers that John A. Roebling received injuries which later caused his death. The work begun by the father was taken up by the son, Colonel Washington A. Roebling, now President of the John A. Roebling's Sons Company.

WILLIAMSBURG BRIDGE

This bridge, completed in 1903, has a main span of 1600 feet between towers, and is supported from four cables, eighteen and three-quarter inches in diameter, each consisting of 37 strands, and each strand composed of 208 wires 0.192 inches in diameter, totaling 7696 wires in each cable. The suspended length of each cable is 2985 feet between center lines of anchorage pins, and the four cables contain a total wire length of 17,432 miles. The ultimate strength of each of these cables is approximately 22,300 tons.

MANHATTAN BRIDGE

The Manhattan Bridge, the latest of the New York City Suspension Bridges, was opened to traffic in 1909 and has a main span of 1470 feet, supported from four cables twenty and three-quarters inches in diameter, and consists of 37 strands. Each strand is composed of 256 galvanized wires 0.195 inches in diameter, making a total of 9472 wires in each cable. The total length of each of these cables is 3224 feet between center lines of anchorage pins. The continuous wire length of the four cables totals 23,170 miles, and the ultimate strength of each of these cables is approximately 28,300 tons.

PARKERSBURG BRIDGE

This bridge was built in 1916 across the Ohio River at Parkersburg, West Virginia, and consists of three spans of 275 feet, 775 feet, and 375 feet respectively. The bridge is supported by two cables each eight and one-quarter inches in diameter, composed of seven strands each having 280 galvanized wires 0.165 inches in diameter, totaling 1960 wires in each cable.

RONDOUT CREEK BRIDGE

This bridge, spanning the Rondout Creek at Kingston, New York, was opened to traffic in 1922, and is one of the more recent bridges supported by cables of Roebling wire. It has a main

span of 705 feet and is supported by two cables nine inches in diameter, consisting of seven strands, each composed of 282 galvanized wires 0.195 inches in diameter, totaling 1974 wires in each cable. Due to the steepness of the backstays, it was necessary to add two extra strands from each tower to the anchorages, these strands consisting of 76 wires, so that each of the backstay cables contained a total of 2126 wires. The total length of wire in both of these cables equals 936 miles, and the strength of each cable approximates 6320 tons for the main span, and 6803 tons for the side spans.

BEAR MOUNTAIN—HUDSON RIVER BRIDGE

The Bear Mountain-Hudson River Bridge was dedicated and opened to the public on November 26, 1924, thus completing, after record progress for this type of construction, one of the longest span bridges in the world devoted entirely to highway traffic. The opening of this bridge provides a greatly needed short route for East and West-bound traffic between New Jersey, Pennsylvania and New York, on the western side of the river, and the New England States on the eastern side, as well as within the Empire State itself.

Crossing the Hudson River from Anthony's Nose, on the east bank, to the site of historic Fort Clinton, at Bear Mountain, on the west bank, about 42 miles above New York City, this bridge provides the first highway, crossing the Hudson River below Albany.

It was at the exact site of this bridge in 1779, while George Washington was concentrating his forces at West Point, and "Mad Anthony" Wayne was storming Stony Point, that the Continental Army stretched huge chains across the river to prevent the British fleet from passing up the river to attack West Point.

The first charter for a bridge at this site was obtained in 1868, and many attempts to undertake construction have been made since. The present charter, however, was obtained during 1921. The contract for construction was signed on March 24, 1923, and work was commenced at once.

This bridge is of the parallel wire cable suspension type with straight "unloaded" backstays. The main span provides a clear unobstructed distance of 1632 feet between the towers, which are situated near the water's edge on each shore. Passing ships have a clearance of 155 feet at the center of span at high tide, which will not endanger the tallest masts or towers. Suspended from the cables is a reinforced concrete highway 38 feet wide with a five foot side walk on each side. The west approach consists of two 50 foot spans, one 100 foot span, and one 210 foot span, while the east approach consists of a single 210 foot span.

The bridge was designed to provide a floor system capable of carrying 15-ton and 20-ton trucks, so as to fully meet the requirements of modern highway traffic. The specified load of 70 pounds per square foot for the general live load on the main span roadway is equivalent to a total of 216 10-ton trucks, or four lines of 54 trucks each.

The two towers are 350 feet high and rest upon concrete piers, carried on solid rock foundations. They have a base width of 89 feet 10 inches and a width of 61 feet 4 inches at the saddle. The batter allows the connections of the main span and approach span trusses to be made between

the columns and on the centerline of the tower. The towers are fabricated from structural steel A. R. E. A. Specifications, except for the saddles and bases, which are of cast steel.

The suspended structure, which is of the deck type, is carried by two cables having a deflection of 200 feet under live load; the backstays are straight except for the sag due to their own weight.

Each cable is made up of 37 strands, each containing 196 wires, making a total of 7252 wires in each main cable, which has a finished diameter, after compacting and wrapping, of 18 inches, and a strength of approximately 23,600 tons. The wire used in these cables is 0.192 inches in diameter before galvanizing, rolled and drawn from acid open hearth steel billets, and has a minimum ultimate strength of 215,000 pounds per square inch after galvanizing. This wire has an average diameter of 0.195 inches after receiving its protective coating of chemically pure zinc, known as galvanizing.

The cables are supported on cast steel saddles at the tower tops and are rigidly fixed to the tower saddles by means of steel casting clamps. The towers, being of the flexible column type, are designed so that their flexure will compensate for any longitudinal movement of the cables, due to variation in temperature or live load stresses.

Each of the cables is anchored into solid rock at both ends of the bridge. The anchorages are made up of 74 I-bars for each cable, or two for each of the 37 strands into which the compacted cable divides at the ends, the wires being carried around cast steel shoes having adjustable pin bearings. The I-bars are pin-connected to other bars of various lengths leading through tunnels into the rock chambers, where the last set of bars is pin-connected to steel castings, which act as shoes to distribute the pressure into the rock. After the erection of the main span, the rock chambers and tunnels were filled with concrete within a few feet of the cable connections. This provides a watertight protection for all the steel members of the anchorage chain.

The floor system and stiffening trusses are suspended from the main cables by means of wire rope suspenders. These ropes are $2\frac{1}{4}$ -inch diameter, 6 x 37 galvanized steel with 7 x 19 independent wire rope center, and have an ultimate strength of approximately 420,000 pounds. A steel casting cable clamp is attached to the main cables at each panel point, and is provided with a properly designed groove over which is passed the bight of each suspender, having both parts connected, by means of open sockets, to transverse beams at the bottom of the stiffening truss. These sockets are pin-connected to an equalizing bar which balances the stress in both parts of the suspender rope.

The stiffening trusses, which are calculated for the required live load of 3160 pounds per linear foot of span, are of silicon-steel with a specified ultimate strength of 80,000 to 90,000 pounds per square inch, and a silicon content of 0.20 to 0.35 per cent. These trusses, spaced 55 feet apart, have a depth of 30 feet, and are placed below the level of the roadway so as to provide an unobstructed view up and down the river from the floor of the bridge. A horizontal truss under the bottom chord is provided to act as a wind bracing. As the clearance required by the United States Government is 135 feet at the shores and 153 feet at the center, the trusses are given a camber of 15 feet which is an advantage in general appearance and gives a grade at the tower which is tangent to the grade of the west approach.

The photographic studies, obtained during the construction of the Bear Mountain-Hudson River Bridge, will present a picture story of the fabrication of parallel wire cable suspension bridges. It is interesting to note that the fundamental principle of parallel wire cable spinning; that is, the aerial spinning process, which was invented by John A. Roebling in 1854, during the construction of the Niagara Falls Bridge; is still accepted to-day as the most practical and economical means of fabricating these huge cables, each containing many thousands of individual wires.

The construction of the cables for the Bear Mountain Bridge may be said to have been the turning point in the history of parallel wire cable fabrication, as several new theories, put to a rigid test during the construction of these cables, proved very successful, and opened the field to cables of practically any diameter and number of wires.

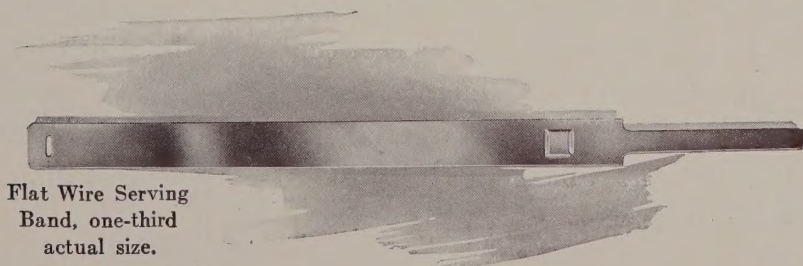
Under the old method of construction the strands when finished were bound together at intervals throughout the entire length of strand by bands of round serving wires. When a sufficient number of strands were completed, seven of the strands in the middle of the cable were bound together to form a central core, and all of the above mentioned round wire servings were removed from the individual strands. After the central core was completed the next outer layer of twelve strands was formed around this core in a similar manner, and each successive layer was formed around these as a core until the cable was completed. The squeezing jacks were then applied and the cable was compacted to its finished diameter. This, it will be observed, was a slow and tedious procedure.

To eliminate this practice, flat wire bands for serving the individual strands were introduced for the first time in the Bear Mountain cables with the idea of leaving them in the finished cable, thus doing away with the necessity of forming the seven strand core and successive outer layers and permitting the cables to be compacted from their true hexagonal formation, as spun, to their finished circular cross-section of precalculated diameter, in one operation. The flat wire bands

were removed from the outer layer of strands only, leaving an appearance of a closely compacted mass of parallel wires around the entire circumference of the cable.



Old Method of arranging Strands for Compacting.



Flat Wire Serving
Band, one-third
actual size.

With the practicability of this method fully demonstrated in the Bear Mountain Bridge, the construction of even larger cables offers no additional difficulties in reference to compacting, as it is only a question of developing sufficient pressure in the squeezing jacks to compact the finished strands from the hexagonal formation, as spun, to the finished diameter desired.

There are, however, a number of factors that become important when designing and constructing large diameter parallel wire cables; namely—

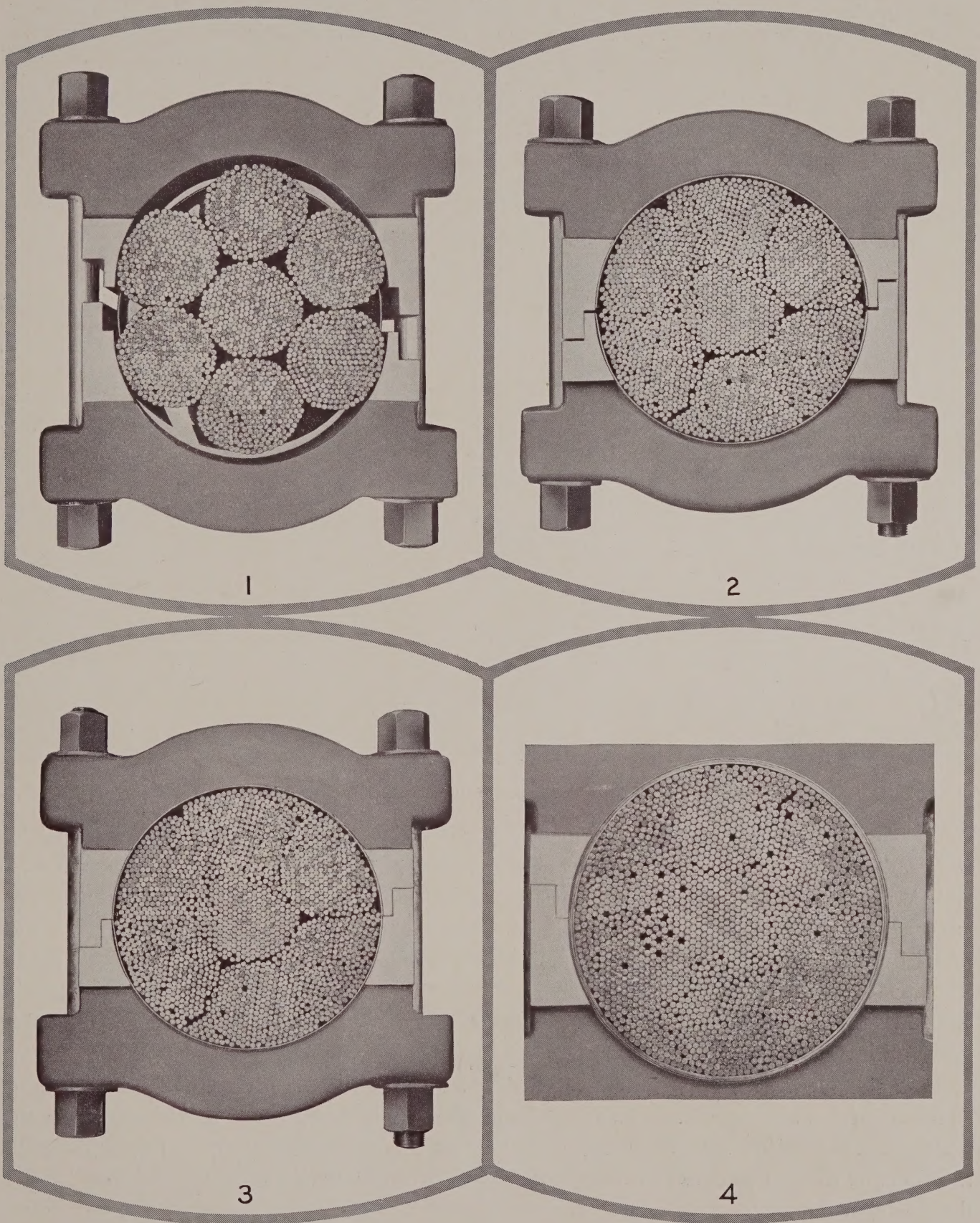
1. Bending stresses in cables due to change in cable curve.
 2. Permissible bearing pressure upon wires in saddles.
 3. Efficiency of strands containing a large number of wires.
 4. Efficiency of wires around strand shoes.
 5. Physical properties of No. 6 gauge galvanized bridge wire.
 6. Coefficient of friction of No. 6 gauge galvanized bridge wire.
 7. Physical properties of suspender ropes.
 8. Construction of temporary foot bridges.
 9. Time study of cable fabrication by the aerial spinning process.
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1. Bending Stresses in Cables due to change in Cable Curve.

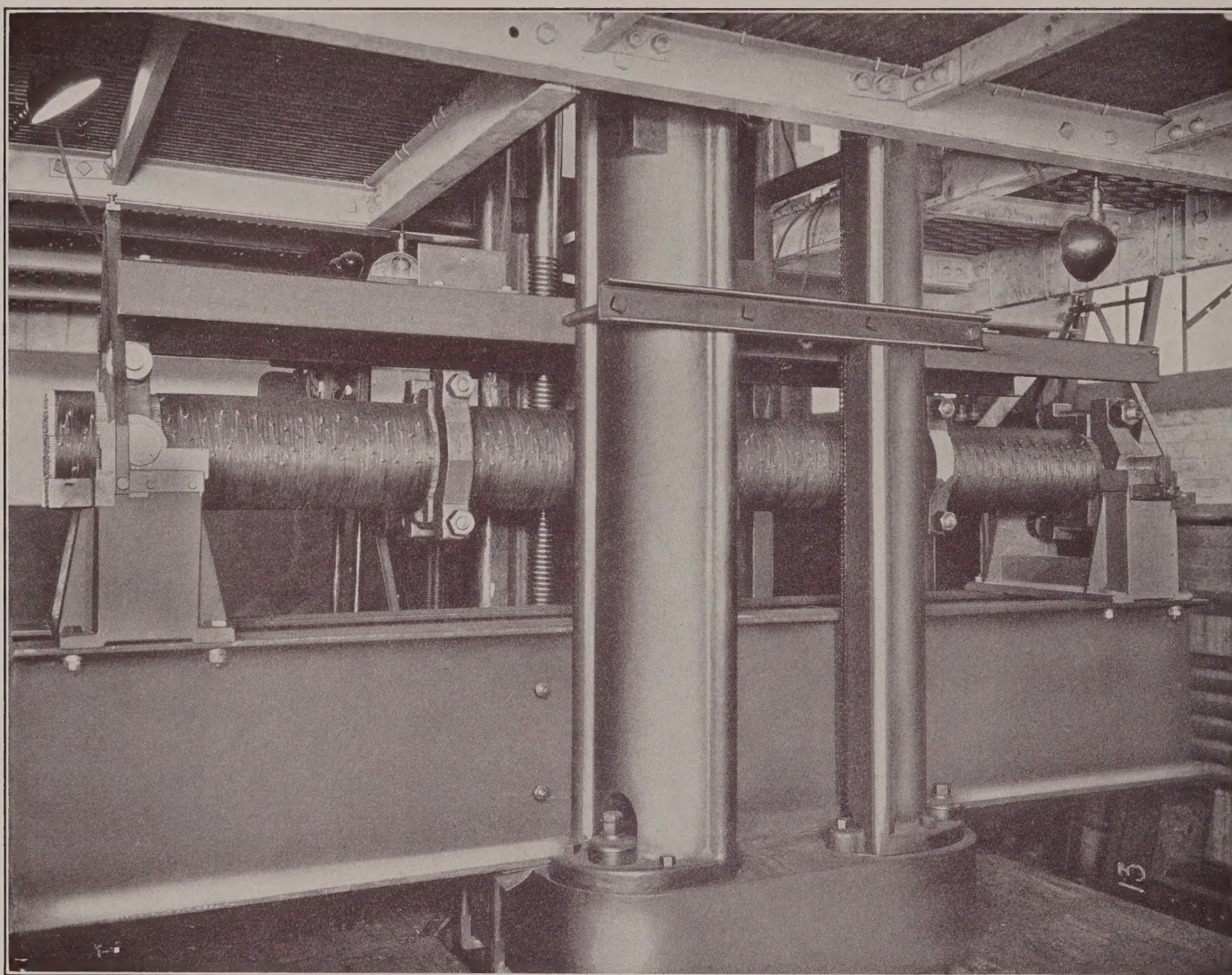
Prior to the erection of the Bear Mountain-Hudson River Bridge, there had been a great amount of controversy between eminent engineers regarding the so-called secondary stresses in parallel wire bridge cables. The theory regarding these stresses is that the change in curvature of the cable at the saddle points on top of the towers, or the change in the angle of departure of the cables leading from the tower saddles, caused by a change in deflection of the cables at the center of span, due to temperature changes and other conditions of loading, will set up secondary or bending stresses in the cables great enough in magnitude to become a consideration of design.

While this theory is fundamentally correct, it is believed that the secondary stresses in a cable of this type are of such small magnitude as to become only a minor consideration of design. To prove that such is the case, extensive tests have been made upon a model cable, the results of which are given for the benefit of those who are interested in this subject, and who may be contemplating the design of cables for long span suspension bridges.

The model cable used in these tests was ten feet long and made up of seven strands, each containing 252 wires, making a total of 1904 individual wires in the complete cable. Each of the wires in the cable was No. 6 gauge galvanized bridge wire, having a diameter of 0.192 inches before galvanized. The finished cable was compacted into a circular section having a circumscribed diameter of 9.4 inches, which, comparing the total gross area of the 1904 wires with the included area of a 9.4 inch diameter circle, contains only 18.09 per cent. voids. This is very significant, as bridge cables fabricated by the aerial spinning process contain from 20 to 23 per cent. voids in their final compacted mass, and therefore the cable under test will be far more susceptible to secondary stresses than those in actual bridge service.



COMPACTING THE MODEL TEST CABLE.



Model Cable and Apparatus used in Bending Tests.

To maintain this compacted diameter of 9.4 inches the cable was tightly clamped by means of five heavy circular steel casting clamps placed at the center, six inches from each end, and at the quarter points. Between these clamps a continuous serving of 0.105 inch diameter soft annealed wrapping wire was applied by hand. The average tension in this wrapping wire was found by test to be approximately 96 pounds, which is believed equivalent to that applied to similar cables in actual bridge construction. The effect of the tight clamps at the quarter points should closely approximate the action of cable clamps in bridge construction, if not to a greater degree of intensity, due to their very close spacing.

The cable was then placed horizontally in a 400,000 pound Olsen Vertical Testing Machine equipped with an automatically balanced beam, the center clamp receiving the load from the moving head of the machine through a vertical plunger made of hard wood, and the end clamps transmitting the end reactions to a pair of 20-inch I-beams resting upon the weighing base of the machine.

The end clamps were designed with cylindrical projecting trunion pins on each side, the trunion pins being free to rotate in circular grooves bored in special bearing blocks, which in turn

were free to slide longitudinally on the bearing castings attached to the I-beams. The exact length of the cable beam was nine feet, measured from center to center of the trunion pins on the end clamps. This arrangement of apparatus was calculated to maintain a free end condition for the cable supports.

Six Wissler Dials were attached in pairs to the center and quarter-point cable clamps, for the purpose of giving the deflection of the cables at these points. In addition, five Ames Dials were placed at each end, so as to indicate any vertical deflection of the ends due to the flexure of the I-beams; any longitudinal motion of the bearing blocks due to the shortening of the cables from deflection; and any longitudinal motion of the ends of the cable at the top and bottom due to its deflection under load.

A more comprehensive idea of the model cable and apparatus described above can be obtained by referring to the photographs on pages 11 and 12.

The results of this test, which we will designate as Test "A," are shown on Charts I and II. Before commenting upon these results, a description will be given of the subsequent Tests "B" and "C."

After study of the stress-strain diagram and deformation chart of the results of Test "A," it was observed that the tightness of the clamps at the quarter and end points had quite a restraining effect upon the resulting cable curves. In order to study this influence, it was decided to make a second test upon this cable, after removing the clamps from the quarter points and serving the intervening space with 0.105 inch diameter wrapping wire, so as to make the wrapping continuous between both ends and the center clamp. To eliminate any restraining action at the end clamps, the bolts holding these clamps were loosened, so that the clamps would simply act as free saddles at these points. The load was applied to the cable at the center clamp, which was equipped with Wissler Dials, as in Test "A," and curves "B" on Charts I and II were plotted from the results obtained.

The curves shown on Chart II represent the actual contour of the cable after the completion of each test, and were obtained from actual measurements taken between a carefully leveled straight edge and the top of the cable by means of a depth micrometer. The vertical measurements are plotted to a 10 to 1 magnification.

Referring to Chart II, it will be observed that Curve "A" is considerably distorted at the quarter points, indicating the influence of the clamps upon the rigidity of the cable. The difference in magnitude of the deflection at the two quarter points is probably due to the difference in tension in the bolts holding the two clamps. On Curve "B" the removal of the clamps at the quarter points has eliminated the restraining action at these points, and the curve follows a fairly even contour representing a greater degree of flexibility. In fact, by referring to Chart I, it will be noted that it was impossible to impose as great a load upon the cable in Test "B" as was done in Test "A" due to the great change in flexibility of the model cable during the second test. The slight distortion of the lowest point to the right of the center line on Curve "B", Chart II, is due to a slight eccentricity in the application of the load.

The difference in characteristics of the two Curves "A" and "B", Chart II, suggest that the stiffness of a parallel wire cable might be influenced by the tension in the wrapping wire, and

to determine whether this is true, a third test, designated as Test "C," was made in the following manner:

The cable was removed from the testing machine, placed in a lathe, trued up to parallel alignment, and continuously served with a higher carbon steel wrapping wire of 0.063 inch diameter, applied under a uniform tension of 200 pounds. In serving the wrapping under this tension a resulting radial pressure of 676 pounds per square inch of outside cable surface was obtained. This pressure is believed to be about three and one-half times that obtained in actual practice.

The tightly wrapped cable was again mounted in the testing machine in the same manner as in Test "B," with the exception that the load was applied directly to the wrapping wire on top of the cable at the mid-point of the span with all clamps removed except the two end clamps, which, as in Test "B," were utilized only as saddles.

In making these tests, the movable head of the testing machine was run at a speed of one-thirtieth of an inch per minute, which, compared with the length of the model under test, produced a rate of change in cable curvature much greater than any that would occur under actual service conditions.

When making the three tests presented herein, the loads were held at several points along the curve for certain intervals of time, while the beam of the testing machine was kept balanced. In each case, while the beam was thus balanced, it was observed that the cable continued to deflect, indicating that the rate at which the cable was deflecting was not directly proportional to the rate of load application. This is significant, as it indicates that such a cable has not the characteristics of a homogeneous beam, but is simply a flexible cord.

Several times, during each of these tests, the loads were reduced to zero, and again applied until the returning curve met and continued the contour of the major curve. Readings of the Wissler Dials were taken at intervals while the load was being reduced to zero and again applied. It was observed that the curves plotted during the re-application of the load continued on a similar pitch for a greater period of time than on the first stressing curve, until they broke over into the contour of the major curve. This characteristic is due to the cable being unable to entirely recover its original horizontal position after the load was removed, and therefore, when the load was again applied, its relative deflection was somewhat retarded, until it approached the maximum load it carried prior to its return to zero. Due to the fact that the rate of deflection of the cable is not proportional to the rate of loading application, the actual speed at which the load is applied will therefore affect the characteristics of the resulting curve.

Referring to Chart I, a straight line curve will be observed at the extreme left of the chart. This curve represents the calculated deflection of a homogeneous beam having a circular section of equal metallic area with that of the cable under test. This curve may therefore be used as a basis for comparing the results of the three tests. The conclusion to be drawn from this chart is, that up to an applied load of 800 pounds, the cable acted like a homogeneous beam. After the loads exceeded this value, slipping occurred between the wires, which allowed greater deflection than those due to the bending moments, until, when the test was completed, the deflection of the cable was found to be many times that of a homogeneous beam.

The effect of the wrapping wire upon this slipping and resulting deflection is clearly indicated by the difference in characteristics of the three curves representing these tests. It will be noted that Curve "C" more closely parallels the curve for the homogeneous beam than either of the two, until a load of 12,500 pounds is reached, and that beyond this loading the deflection is not as rapid as in either Test "A" or "B." These facts indicate that the increased intensity of compactness of the cable in Test "C" has decreased its flexibility to some extent and increased the minor bending stresses, which can be materially reduced and rendered insignificant by proper application of the wrapping wire in compacting.

It should be understood that the data obtained from these tests is presented only as a study and as a basis from which additional tests can be made if a further investigation of this subject is desired. The various curves presented show only relative values, as in order to definitely formulate these theories, the time element in applying the load must be taken into consideration. The speed of load application also enters into the problem. To determine the exact influence of these factors, it would be necessary to supplement this study with additional tests, but it is thought that the data presented will clearly indicate that secondary stresses in parallel wire bridge cables are of minute consideration in design; when the effects of improper compacting as well as of incorrectly designed clamps and excessive pressures applied to them when attaching, are borne in mind.

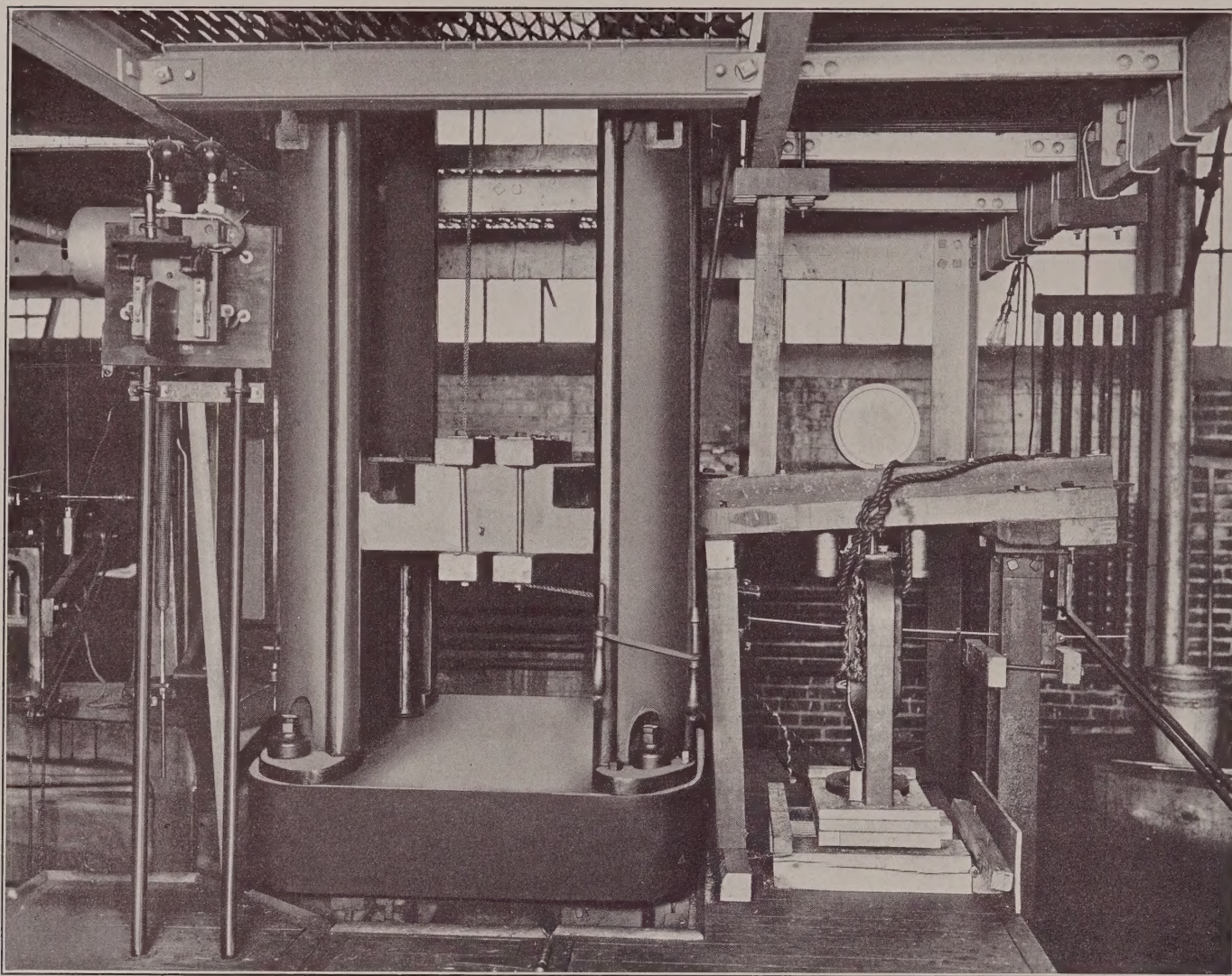
2. Permissible Bearing Pressure upon Wires in Saddles.

In order to determine the effect of pressure upon bridge wire under tension, tests were made upon short lengths of 0.195-inch diameter galvanized bridge wire, which were subjected to various pressures. At the same time tensions were applied to them ranging from zero pounds up to the ultimate strength of the wire. The pressures were applied to the wires by means of a Brinell Hardness Machine calibrated for pressures up to 4,000 kilograms. The tensions were exerted by a 400,000 pound Olsen Vertical Testing Machine. Photographs of the apparatus used in these tests are shown on pages 16, 17 and 18.

To approximate the conditions encountered by the bottom wires in the cable at the tower points, *i. e.*, those in contact with the saddles, the wires under test were placed upon two 1" lengths of similar wire laid into special grooved blocks 1" in length, and later $\frac{1}{2}$ " and $\frac{1}{4}$ " in length, to obtain an increased unit pressure with the Brinell Machine. Care was taken to have the wire straight when the tension approached the ultimate strength to avoid any bending stresses.

Chart III shows the pressures applied and the corresponding ultimate strengths which were obtained. It will be noted that for a pressure of 5,500 pounds per linear inch, an ultimate strength of 6,160 pounds is obtained, showing a loss of strength of approximately $4\frac{1}{3}$ per cent. In all cases the wires broke under the blocks.

To approximate the conditions of the inner wires in the cable, similar tests were made, with the exception that two wires were placed above as well as below the wire under test. The blocks in this case were 1" long, and the four short wires, 2" long, extending past the block $\frac{1}{2}$ " on each side. Six wires were tested under an applied pressure of 3,300 pounds, and the average

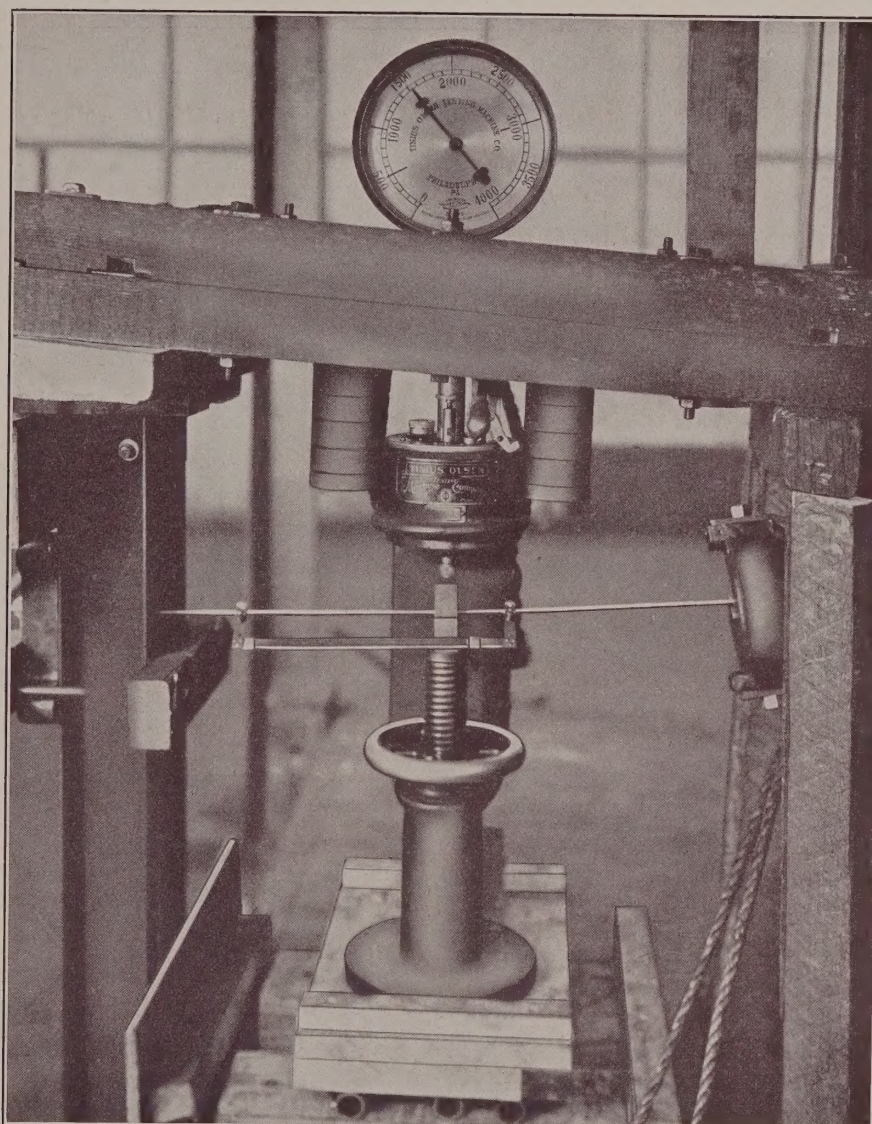


Olsen and Brinell Machines showing method used to determine Bearing Pressures.

loss in ultimate strength due to the applied pressure was found to be only 0.43 per cent. indicating that the results of such a pressure are negligible.

Similar tests were made to determine what effect pressures applied and released, while the wire was stressed to various tensions below its elastic limit, had upon the ultimate strength of the wire. The 1" blocks were used and 3,300 pound pressure applied until the tension values were 1,000 pounds, 2,000, 3,000, 4,000, and 4,300 pounds respectively. The pressures were then released, the pressure blocks removed, and the tensions carried up to the ultimate strength of the wires. From the results of these tests, it was found that pressures up to 3,300 pounds per linear inch, applied and released before the wire had been stressed to its elastic limit, had no effect upon the ultimate strength of the wire.

To determine the effect that combined pressure and tension have upon the elastic limit of the wires, tests were made with the wires under various pressures and Wissler Dial readings were taken to indicate elongation with reference to the tension applied. The results are shown on the stress-strain curves, Chart IV, which were made from the Wissler Dial readings taken on the wire when under the pressure indicated beside the curve. The master curve was made by



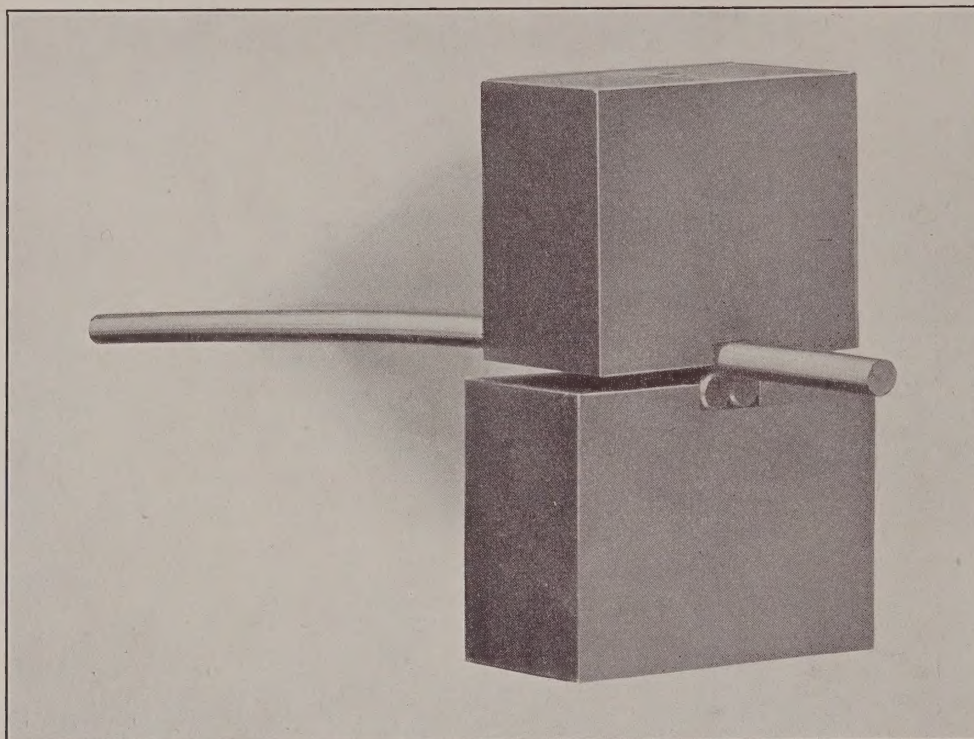
Brinell Machine used in Tests.

averaging a series of tension tests made upon specimens from the same coil. From these curves it will be noted that pressures up to 5,500 pounds per linear inch have little effect on the elastic limit; while pressures in excess of 5,500 pounds per linear inch lowered the elastic limit to an appreciable degree.

3. Efficiency of Strands containing a large number of Wires.

To determine the efficiency of parallel wire strands, a strand consisting of 37 No. 6 gauge galvanized bridge wires of varying strengths and elastic limits was made and both the strand and individual wires forming it were subjected to ultimate strength tests.

Chart V shows a stress-strain curve for the 37-wire strand, and the average wire curve for the 37 individual wires, on the basis of a 48'' length under test. The table inserted in the chart gives the data for the wires arranged in order of their ultimate strengths in pounds. It will be noted that the ultimate strength of the weakest wire practically corresponds to the first wire break



Special Grooved Blocks, showing method of applying pressure to the wires.

in the strand, and also that the wires which were observed to break, broke in the order of their ultimate strengths. It will be further noted that the strand curve and average wire curve coincide up to the elastic limit of the strand, and that the strand curve starts to leave the average wire curve as the elastic limits of the component wires are passed. It is therefore evident that the lowest elastic limit of the component wires will govern the elastic limit of the strand.

A study of the data presented in Chart V will also indicate that the lowest ultimate strength of the component wires in any strand will govern the ultimate strength of the strand as a whole, as after the load on the strand has caused the first wire to break, thus throwing its entire load upon the remaining wires, an accumulative action takes place, due to the remaining wires being forced to take up the load released by the previous wire breaks, until a final rupture of the strand occurs.

4. Efficiency of Wires around Strand Shoes.

In order to determine whether the ultimate strength of a 0.195" diameter galvanized bridge wire would be affected by being bent around a strand shoe, the following tests were made.

A sheave was turned to a tread diameter of 18" with a square groove .197" wide and deep enough to accommodate a single loop of bridge wire. The sheave was placed on the stationary head of the testing machine and the ends of the wires were fastened to the moving head. A number of wires were broken in this manner, giving an average of 6,145.5 pounds for the wire strength.

Three wires from the same coil were then broken in the ordinary manner (regular wire test) giving an average value of 6151.67 pounds. These figures and the fact that in all tests with the

sheave the breaks did not occur on the sheave or near it, but in the straight section well toward the moving head, would indicate that a bend to a 9" radius does not influence the ultimate strength of the wire.

5. Physical Properties of No. 6 Gauge Galvanized Bridge Wire.

Charts VI and VII show the average results obtained by stressing 10" specimens of No. 6 gauge galvanized bridge wire to their ultimate strength. The curves contained in these charts are self explanatory.

It will be noted from Chart VII that by subjecting the wire to multiple stressings, or increasing and releasing the tension applied by degrees until the neighborhood of the elastic limit has been reached, the true elastic limit is obtained.

To determine whether or not the outside surface or skin of bridge wire is stronger than its center, five tests were made with specimens of this wire, the middle section of the test samples being ground for a length of $1\frac{1}{2}$ " to diameters of 0.184", 0.174", 0.149", 0.123", and 0.099" respectively. In making the five test samples mentioned above, which were cut from the same coil, adjacent lengths were taken for ultimate strength tests, on the basis of gross and net cross-sectional area. The results of these tests are tabulated below:

	Actual Ultimate Strength in Pounds.	Ultimate Pounds per Square Inch.
Average for No. 6 Gauge Wire (5 tests) on basis of .193" Gross Diameter (including galvanizing)	6429.6	219,777 (Gross Area)
Average for No. 6 Gauge Wire (5 tests) on basis of .189" Net Diameter (galvanizing removed)	6429.6	229,215 (Net Area)
Test on Wire Turned to .184" diam.	6150	230,625
" " " " " .174" diam.	5538	232,873
" " " " " .149" diam.	4126	236,626
" " " " " .123" diam.	2776	233,619
" " " " " .099" diam.	1766	229,425

6. Coefficient of Friction of No. 6 Gauge Galvanized Bridge Wire.

In order to determine the coefficient of friction for galvanized bridge wire to be used in determining the proper bored surface for cable bands, and the proper bolt pressure to be used to prevent any slippage of such bands while clamped around parallel wire cables, tests were made upon No. 6 gauge galvanized bridge wire as follows:

The wire under test was firmly clamped in the groove of a carriage which was free to move in a horizontal plane. Sliding blocks 1" long with bearing face either smooth or corrugated were balanced on top of the test wire. Pressure was applied on the sliding blocks by means of a suspended weight acting through a knife edge. These blocks were also attached to a weighing drum which measured the resistance offered by the blocks to movement of the bridge wire beneath.

Preliminary tests were made using smooth and corrugated blocks, which proved conclusively, especially in the case of heavy loadings, that the coefficient of friction for the smooth bearing surface is too low to be considered, therefore, subsequent tests were made only with corrugated blocks.

The corrugations in the blocks were made by the cutting tool in a shaper. Two types of corrugations were used; one having 32 shallow tool marks across the 1" face of the block, specified as medium; and the other having 17 fairly deep tool marks across the 1" face of the block, specified as rough. The corrugations in both blocks were cut so that when the blocks were placed in the testing machine, the corrugations would be at right angles to the travel of the test wire.

Tests were made using clean galvanized wire, and also galvanized wire which had been coated with thin and thick applications of 98 per cent. and 85 per cent. red lead. Readings were taken of the starting and sliding values registered on the weighing drum under pressures of both 103 and 259 pounds applied to the blocks.

The results of these tests indicate that the average coefficient of friction for clean galvanized wire was approximately .15 for the medium block and .17 for the rough block; while that for painted galvanized wire was approximately .19 for the medium block and .21 for the rough block. It was interesting to note that the difference in the constituency of the paint applied did not affect the resulting coefficient of friction.

7. Physical Properties of Suspender Ropes.

Chart VIII contains the average results obtained by testing two samples of $2\frac{1}{4}$ " diameter 6 x 37 galvanized steel suspender rope with 7 x 19 independent wire rope center in the 400,000 pound Olsen Vertical Testing Machine. The ropes were first stressed to 158,500 pounds, the maximum stress to which they would be subjected in service, and held for a period of thirty minutes, during which time the stretch in the cable was .0155" in a length of 60". The modulus of elasticity obtained was 16,868,000 pounds per square inch. The tension was then released and the second curve, on which the modulus of elasticity is 19,737,500 pounds per square inch, was obtained by stressing the ropes to 100,000 pounds, which tension is slightly above the average working stress to which these cables would be subjected when in service.

The tension was again released to zero and then carried to 390,000 pounds, or very nearly the capacity of the testing machine, and the third curve with a modulus of elasticity of 20,400,000 pounds per square inch was obtained for tension not exceeding 160,000 pounds. This curve shows an increase in the unit elongation above 160,000 pound tension, which increase is due to structural stretch. Had the ropes been subjected to a tension of approximately fifty per cent of their ultimate strength for a period of a few hours before taking the readings for the third curve, the structural set would have been practically removed and the curve would have been a straight line with a modulus of elasticity of at least 20,400,000 pounds per square inch up to the true elastic limit, or approximately 278,000 pounds.

The first stressing curve indicates a structural stretch due to holding a tension of 158,500 pounds for a period of thirty minutes. Any tension above 158,500 pounds will cause additional

structural stretch or set, and therefore the true elastic limit of the rope can only be determined by multiple stressing. Such tests show the true elastic limit to be approximately sixty per cent of the ultimate strength. In other tests which have been made upon this rope the ultimate strength was found to be 463,000 pounds.

8. Construction of Temporary Foot Bridges.

In order to fabricate parallel wire bridge cables by the aerial spinning process, it is first necessary to make the bridge cables, while under construction, accessible throughout their entire length from anchorage to anchorage. It is also necessary to support the aerial rope tramway, used in the spinning of the strands, at various points on each span.

To attain these objectives separate foot bridges are erected directly below and about three feet from the final contour of each of the proposed cables. The width of these foot bridges varies between six and fourteen feet, depending largely on the size of the main cables, since the bridges must be wide enough to permit the spinning of two strands on each side of the line of the proposed cable, as well as to allow the workmen freedom of movement and easy access to the cable during all stages of its fabrication. Connections are established between the foot bridges at various intervals, usually at the mid and quarter points of the spans, by means of trussed cross bridges so that easy communication is afforded from all parts of the structure. These cross bridges also serve to stiffen the foot bridges laterally in conjunction with a system of storm cables suspended below the foot bridges in the form of an inverted parabola, the storm cables being anchored to the tower bases and the connection to the foot bridges being made at various intervals by vertical guys. The aerial rope tramway is supported by towers which are erected on the foot bridges and spaced to provide efficient tramway operation.

The whole structure is supported by lengths of galvanized wire ropes stretched from anchorage to anchorage, and passed over the tops of the towers in saddles especially provided for them. It is standard practice to make these foot bridge ropes to meet the specifications of the suspender ropes in the finished bridge, so that upon the completion of the work of spinning and compacting the cable, the foot bridges may be suspended from the cable itself by means of wire rope lashings at proper intervals, and the foot bridge ropes removed and cut into the proper lengths to be used as suspender ropes. The foot bridges are thus left in place to be used in the final wrapping of the cables.

The maximum stresses in the foot bridges being determined, enough lengths of foot bridge rope are used to maintain the proper factor of safety. It is customary to use two groups of two, three, or five lengths each, for each foot bridge, and when the lengths required per group are in excess of two, they are placed in two layers, each group being clamped together at the floor beam points, to maintain a uniform cable throughout its entire length. It is necessary to adjust these ropes with considerable accuracy so that the foot bridges will hang in the proper relation to the proposed cables.

The frame work of the foot bridges, which is of timber construction, consists of a system of floor beams, stringers and braces covered by floor boards with cleats placed upon them to provide sure footing on the steep grades. The timber is framed on the ground, hoisted to the tops

of the towers, carried out on both sides of each tower at the same time, and attached to the ropes in sections, the floor beams resting upon the ropes. It is essential that the work of erection be carried out on each span at the same time, thereby maintaining balanced stresses at the towers.

9. Time Study of Cable Fabrication by the Aerial Spinning Process.

In estimating the time required for the fabrication of parallel wire bridge cables of large diameter by the aerial spinning process, a number of conditions must be taken into consideration. A few of these conditions are the size and total suspended length of the cables; the efficiency of the operating equipment, including labor; and the prevailing weather conditions.

The important factors in considering the cable itself are the number of strands, the number and length of the wires, the efficiency of the wire connections or nipples, and the total tonnage of wire in the cable.

In considering the operating equipment, it again becomes necessary to take into account the suspended length of the cable in regard to the tramway and spinning wheel, which carries the individual wires across from anchorage to anchorage. This leads to the question of tramway towers, speed of the traction rope, winding machine for operating the traction rope, spinning wheel carriages, sheave equipment for both traction rope and wires in process of spinning, and the accessories to these items, together with the difficulties peculiar to each. The labor problem resolves itself into training men for the work and keeping them on the job, thus eliminating excessive labor turn-over.

The prevailing weather conditions are an important factor, since it is obvious that in a high wind or very low temperature it is impossible to work with the same efficiency that is warranted by more favorable conditions. These elements, over which there is no control, cannot be positively foreseen, but the work can be laid out with some consideration as to the climatic conditions of the locality in question.

In regard to the actual time requirements for stringing the wires, it is by no means possible, due to the conditions above, to present an empirical formula which may be applied. It is, however, safe to say that the first twenty-five per cent of the wires strung will consume twice the time that will be required by the next twenty-five per cent. This statement applies in an even more marked degree to the shifting and adjusting of the strands into their final position in the saddles. This, however, does not mean the same rate of increase will be maintained to the completion of the spinning operation, but that after the first twenty-five per cent of the strands have been completed, the workmen are thoroughly familiar with their work and have by this time approached their maximum efficiency.

So many improvements in the equipment used in the process of aerial cable spinning have been and are being made as to make a comparison of time consumed by this operation on different bridges rather vague. The Brooklyn Bridge, completed in 1883; the Williamsburg Bridge, completed in 1903, and the Bear Mountain Bridge, completed in 1924, are good illustrations of this fact. The time required for stringing wires was twenty-one months for the Brooklyn Bridge, seven months for the Williamsburg Bridge, and three and one-quarter months for the Bear

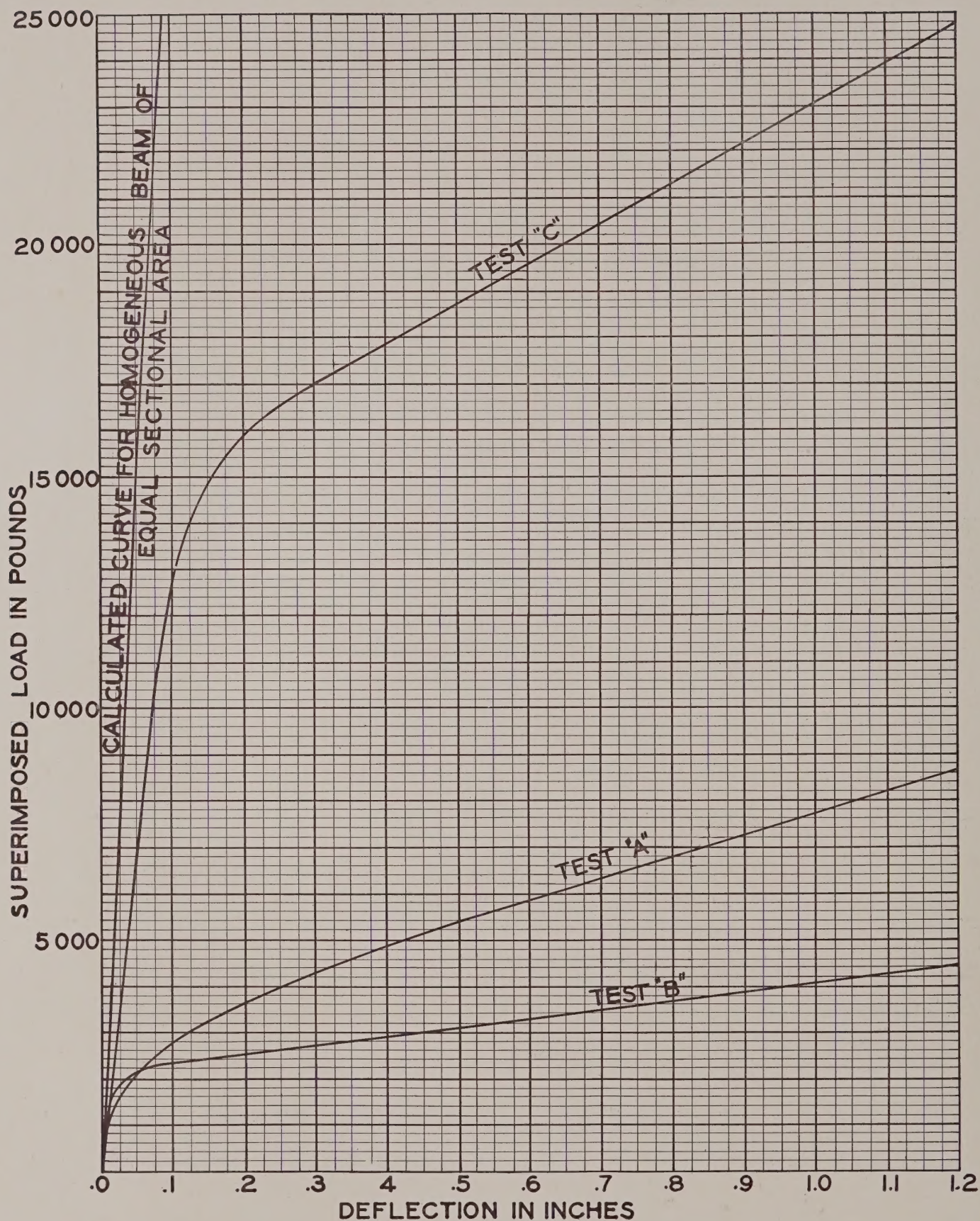
Mountain Bridge. In making these comparisons, however, it must be borne in mind that while the Bear Mountain Bridge has but two cables, both the Brooklyn and Williamsburg Bridges have four cables each, the fabrication of all four being carried on at the same time.

The equipment and method of operation are important factors in accounting for the difference in time required for stringing wires on the three bridges. On the Bear Mountain Bridge, one tramway with two travelling sheaves, served one cable, thus allowing four strands per cable to be strung at a time. On the Williamsburg Bridge, one tramway with two travelling sheaves served two cables, allowing but two strands per cable to be strung at a time. On the Brooklyn Bridge, the equipment was similar to that on the Williamsburg Bridge, but the wires crossed from one side only, whereby but one strand per cable was strung at a time. With these facts in mind, it can be readily seen that the rate of stringing on the Brooklyn Bridge was doubled on the Williamsburg Bridge, and quadrupled on the Bear Mountain Bridge.

On a bridge with longer spans, it is possible to spin more tonnage of wire per day, inasmuch as the actual spinning is not so frequently interrupted by the removal of the wire from the wheel at the end of each trip, and the placing of the next loop around the wheel for its return across the span. In other words, each trip of the wheel, considering the longer span, results in a greater tonnage of wire spun. It is also possible, on the longer bridges, to obtain a greater tonnage per day due to the increased speed and efficiency of tramway operation and other equipment, as well as of shifting and placing the strands in the saddles. Such increases in efficiency, on the larger bridges, are accomplished by the installation of more complete and elaborate equipment, which is warranted by the magnitude of operations carried on.

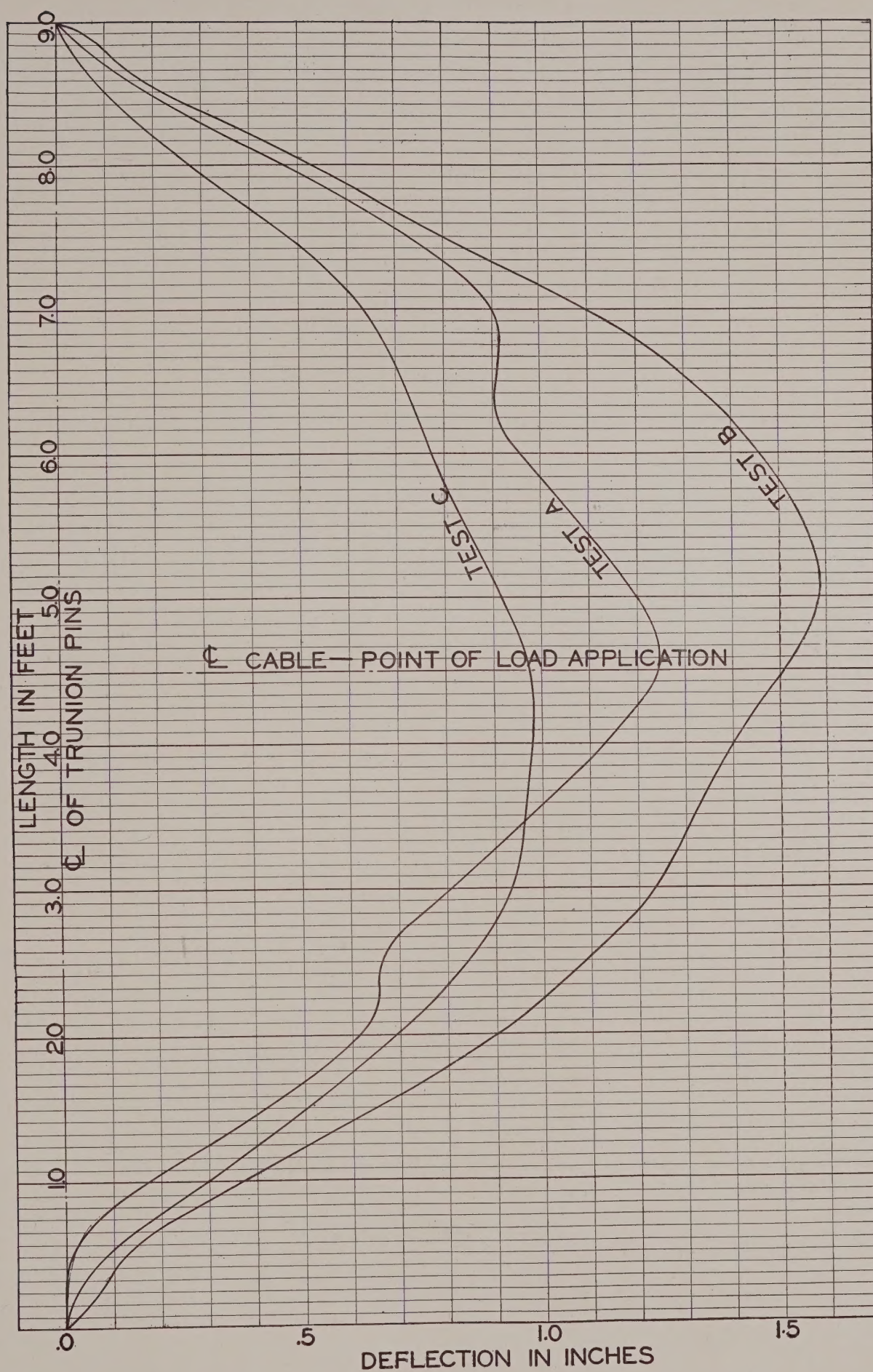
CHARTS.

- I. STRESS-STRAIN DIAGRAM COVERING THREE BENDING TESTS ON MODEL BRIDGE CABLE.
- II. DEFORMATION CHARTS AFTER FINISH OF STRESS-STRAIN TESTS ON MODEL BRIDGE CABLE.
- III. PRESSURE—TENSION CURVE OF BRIDGE WIRE.
- IV. STRESS-STRAIN DIAGRAM WITH BRIDGE WIRES UNDER PRESSURE.
- V. STRESS-STRAIN DIAGRAM FOR 37-WIRE STRAND AND INDIVIDUAL BRIDGE WIRES.
- VI. STRESS-STRAIN DIAGRAM OF BRIDGE WIRE. SINGLE STRESSING.
- VII. STRESS-STRAIN DIAGRAM OF BRIDGE WIRE. MULTIPLE STRESSING.
- VIII. STRESS-STRAIN DIAGRAM FOR SUSPENDER ROPES.



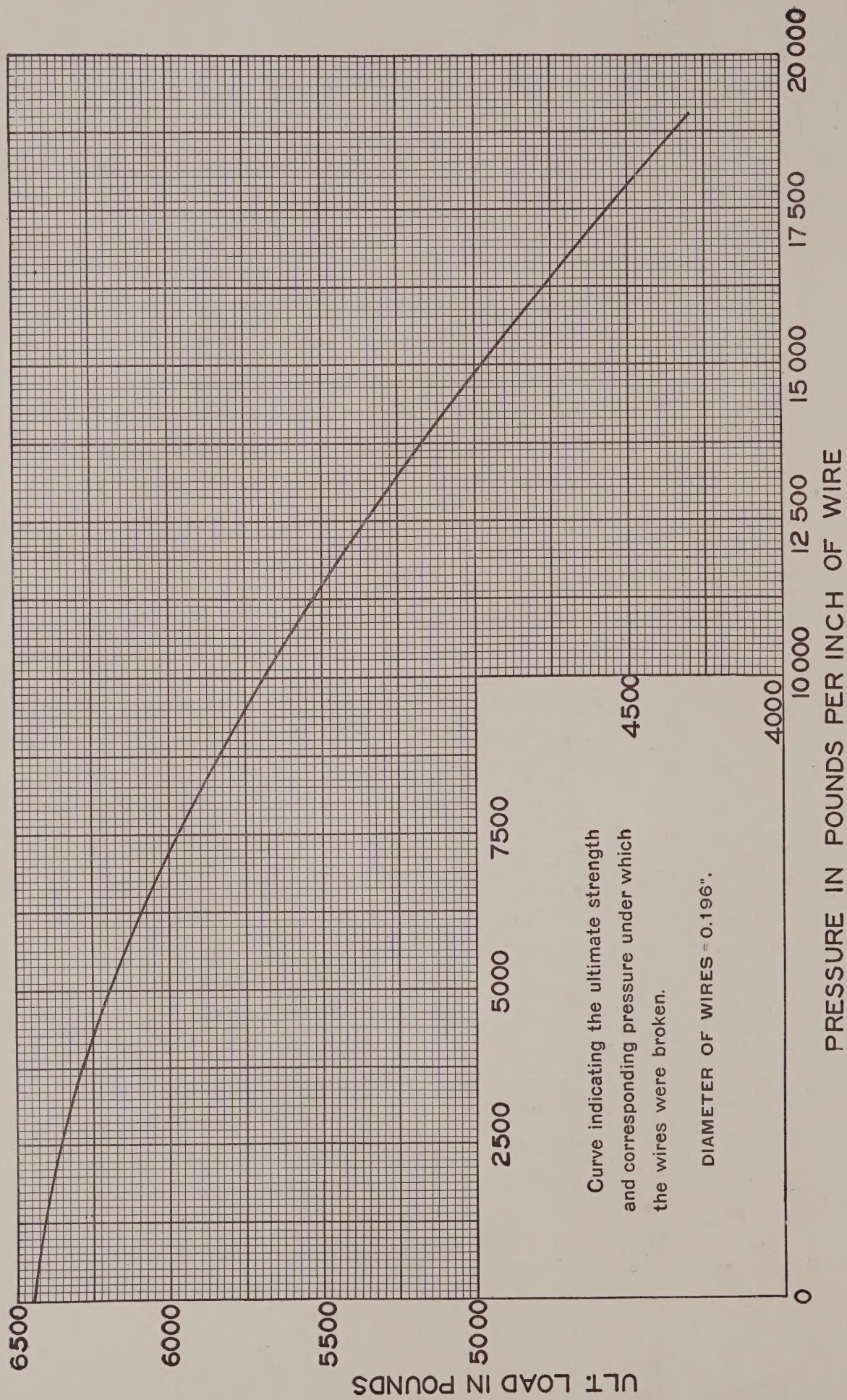
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CHART I.—Stress-Strain Diagram covering three bending tests on Model Bridge Cable.



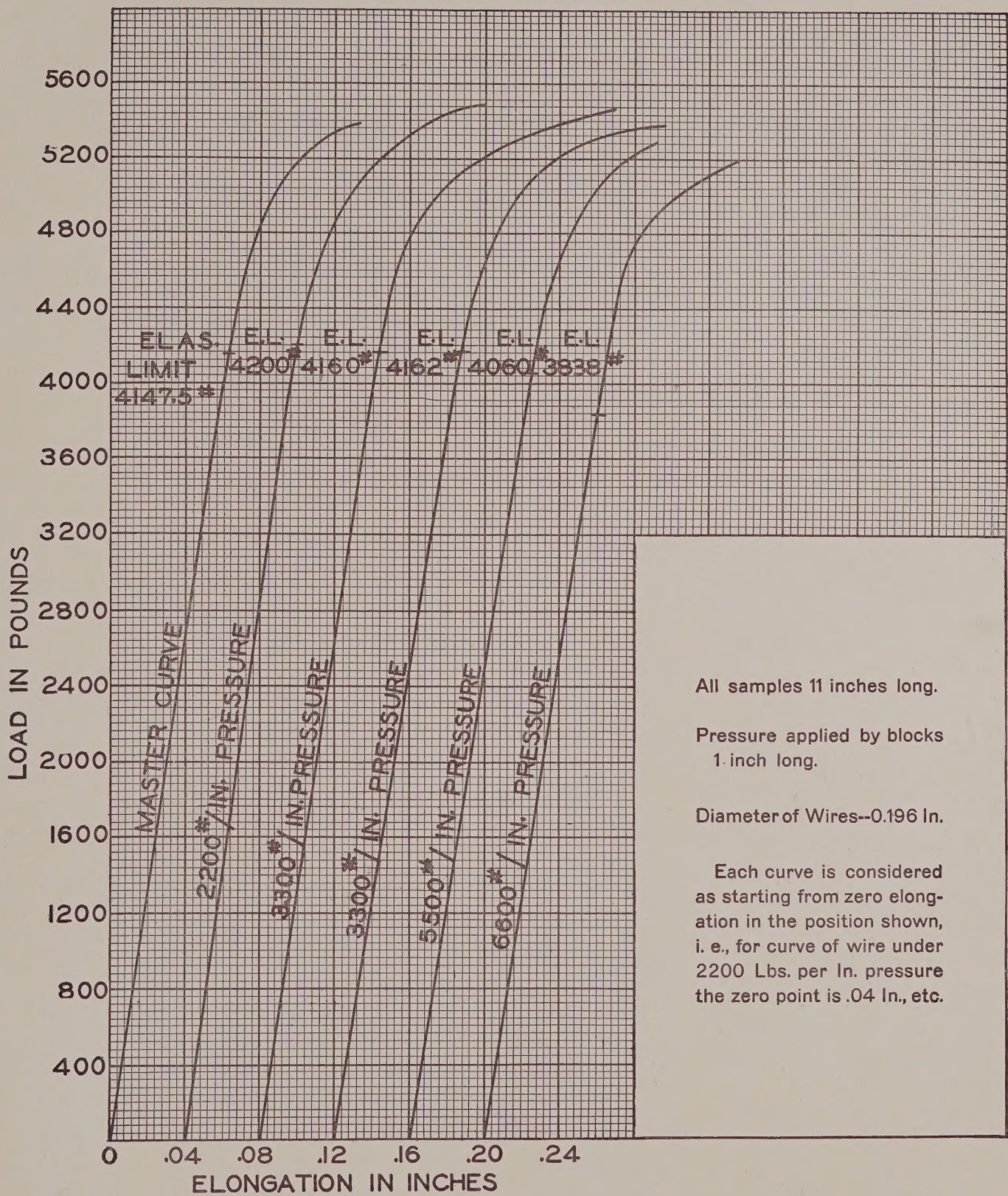
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CHART II.—Deformation Chart after finish of Stress-Strain tests on Model Bridge Cable.



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CHART III.—Pressure—Tension Curve of Bridge Wire.



All samples 11 inches long.

Pressure applied by blocks
1 inch long.

Diameter of Wires--0.196 In.

Each curve is considered
as starting from zero elongation in the position shown,
i. e., for curve of wire under
2200 Lbs. per In. pressure
the zero point is .04 In., etc.

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CHART IV.—Stress-Strain Diagram with Bridge Wires under Pressure.

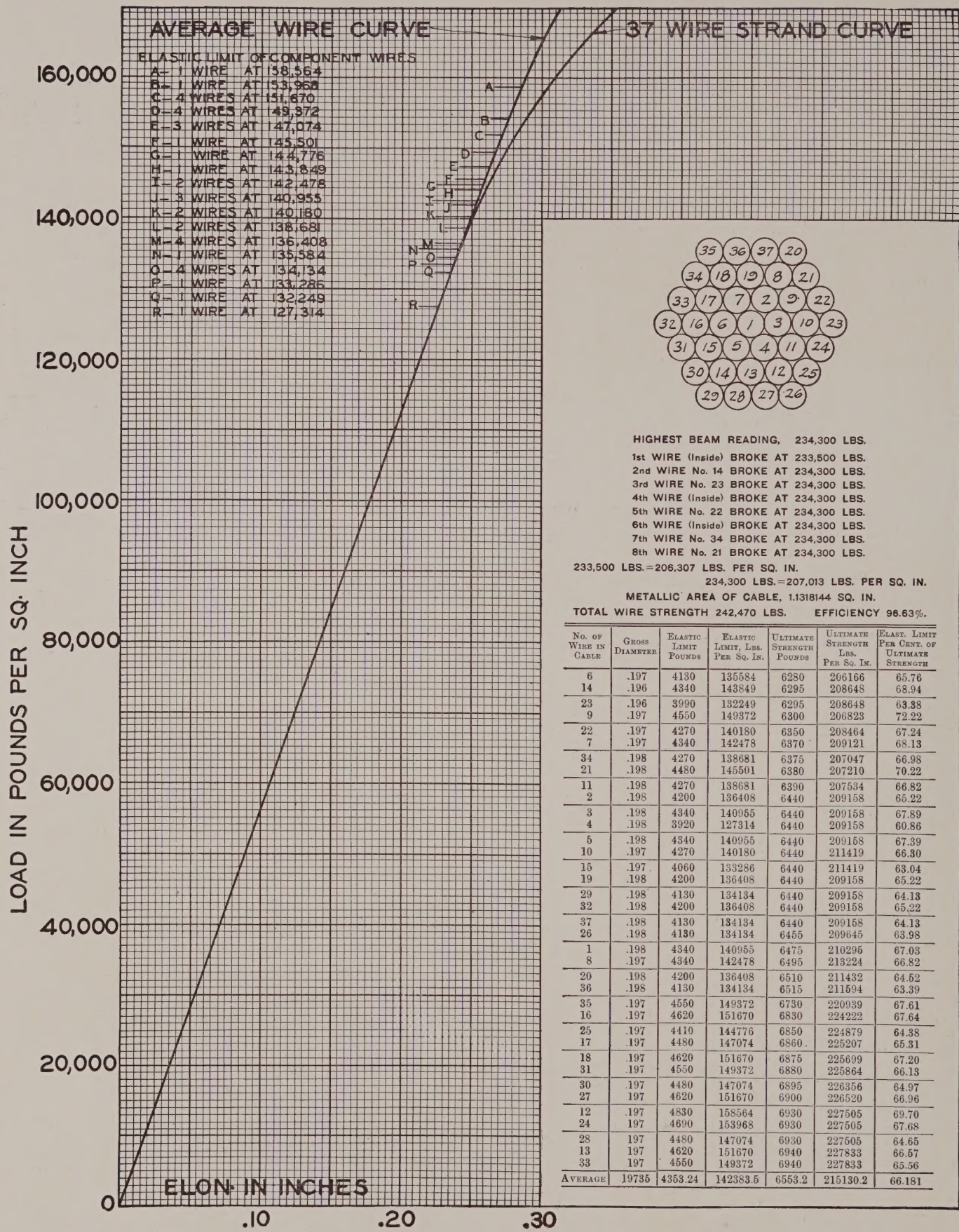
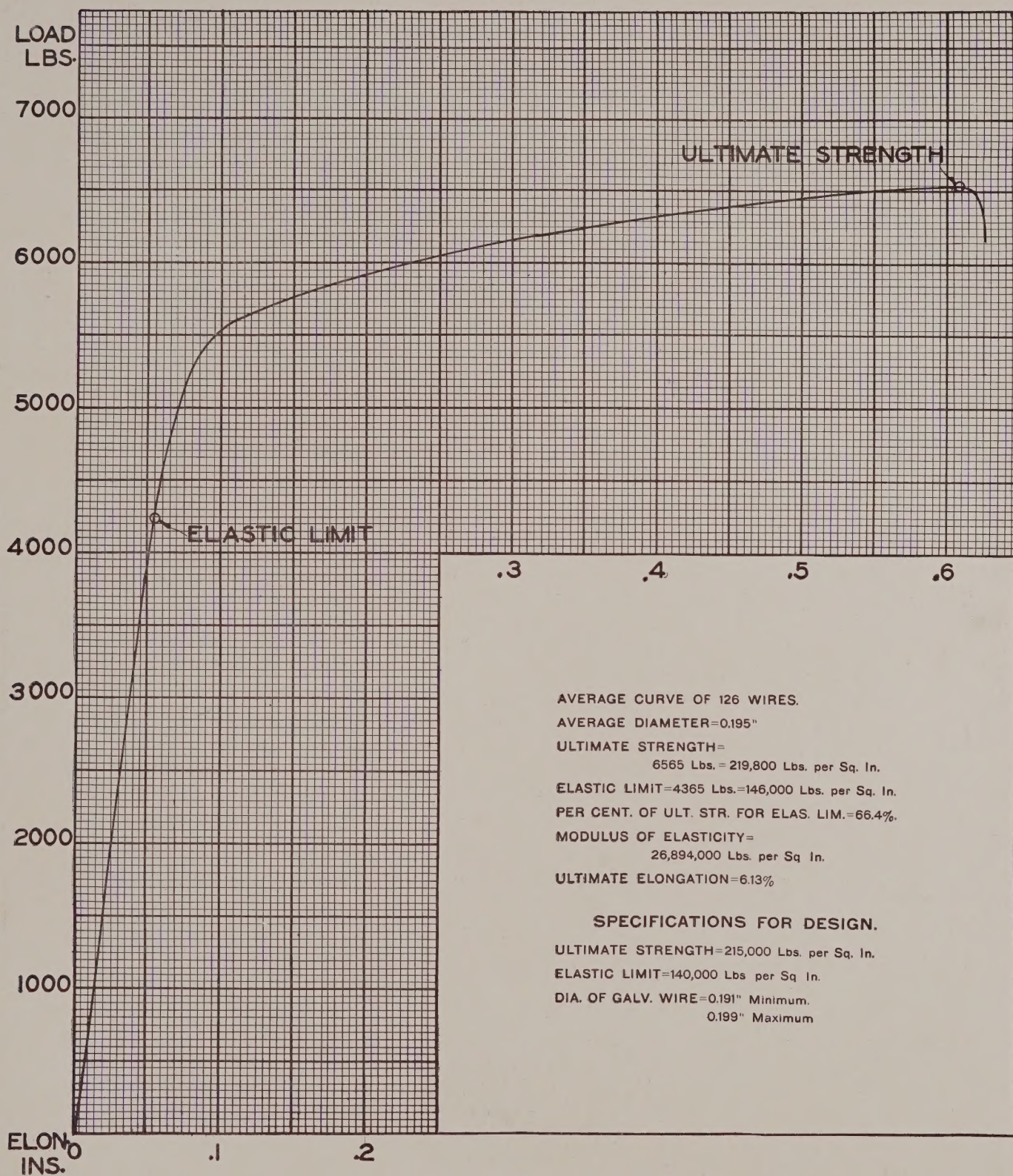
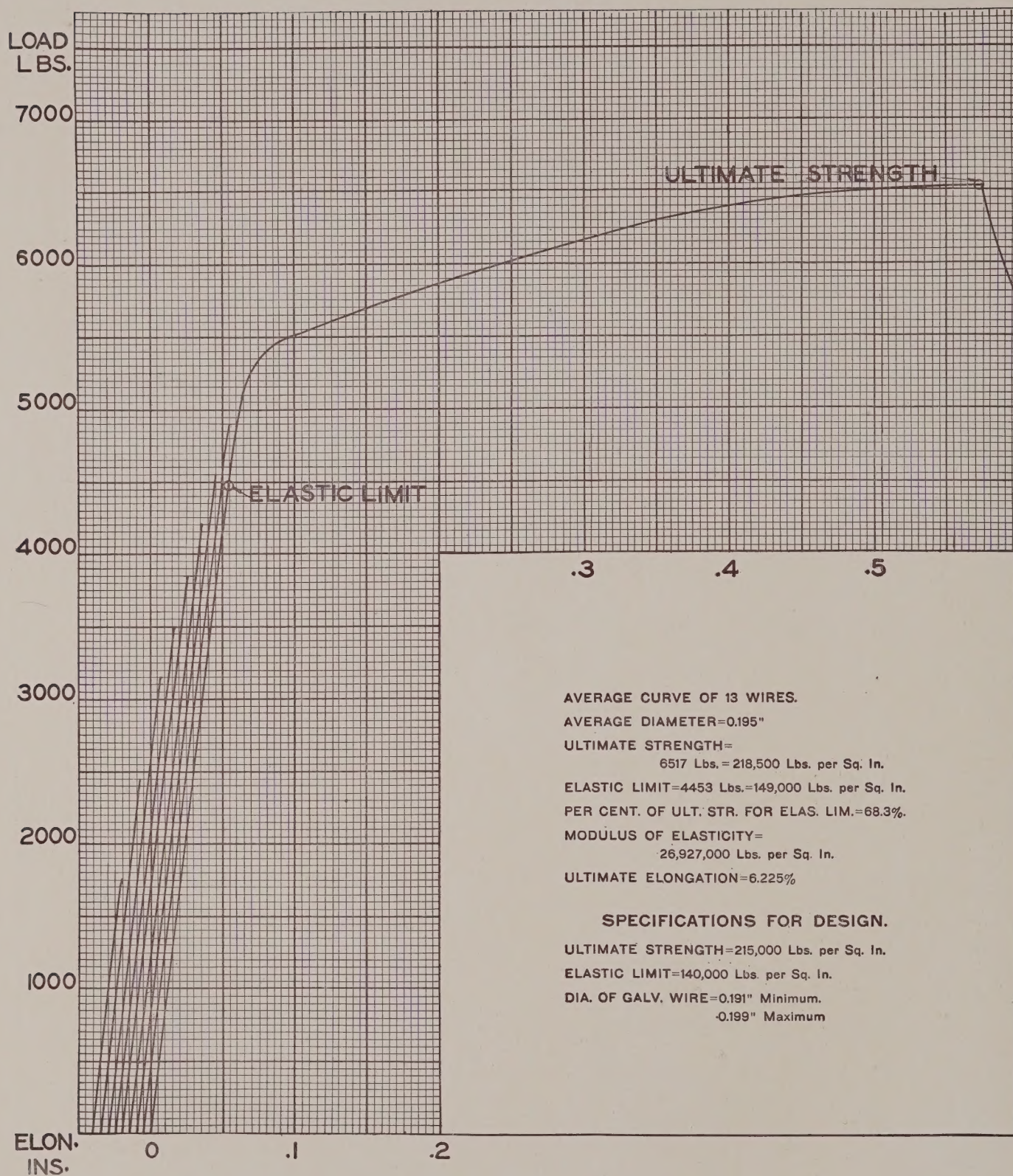


CHART V.—Stress-Strain Diagram for 37-Wire Strand and Individual Bridge Wires.



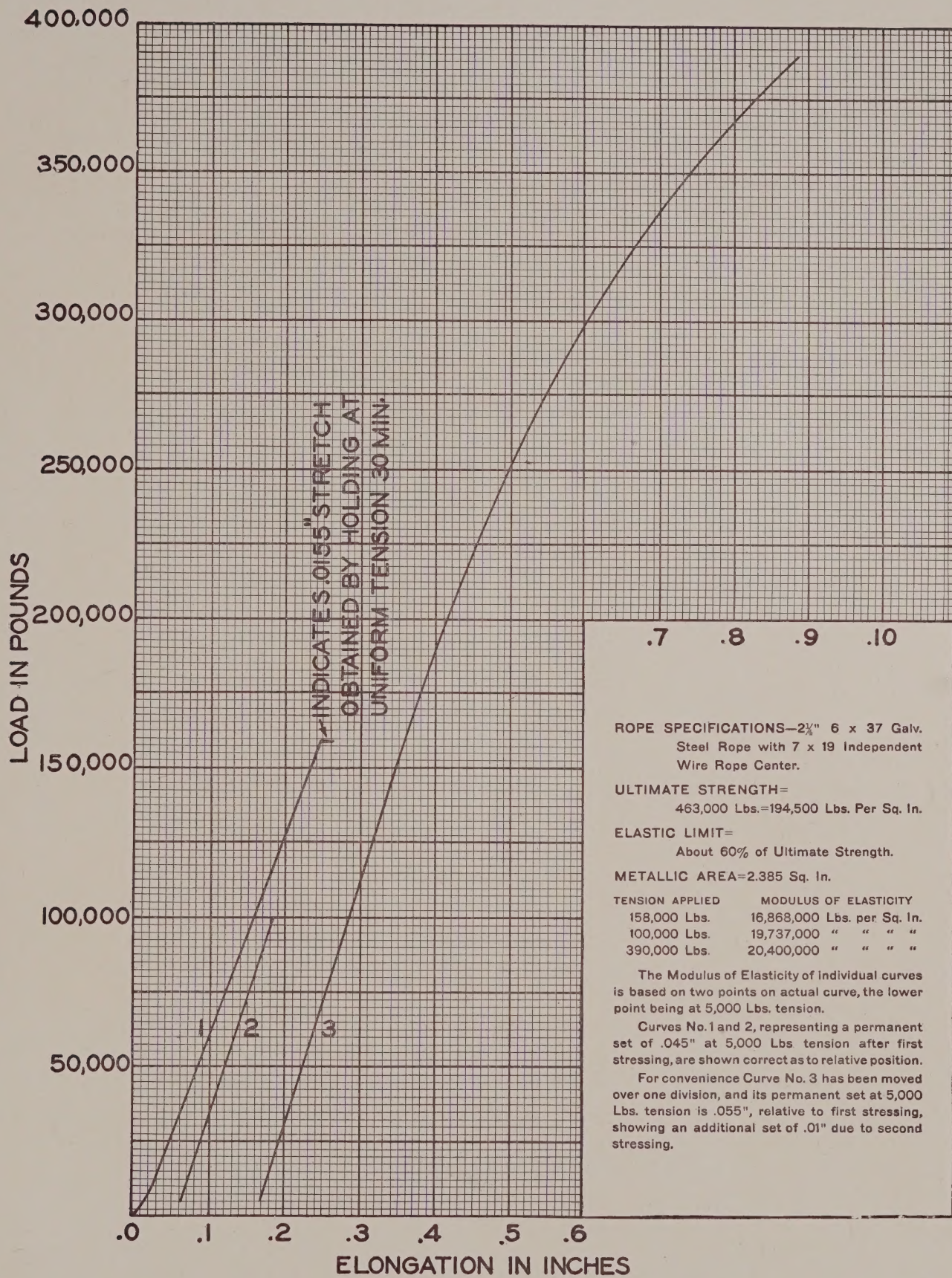
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CHART VI.—Stress-Strain Diagram of Bridge Wires, Single Stressing.



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CHART VII.—Stress-Strain Diagram of Bridge Wires. Multiple Stressing.



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CHART VIII.—Stress-Strain Diagram for Suspender Ropes.

*Photographic Studies made
during the erection of the Bear
Mountain--Hudson River Bridge*

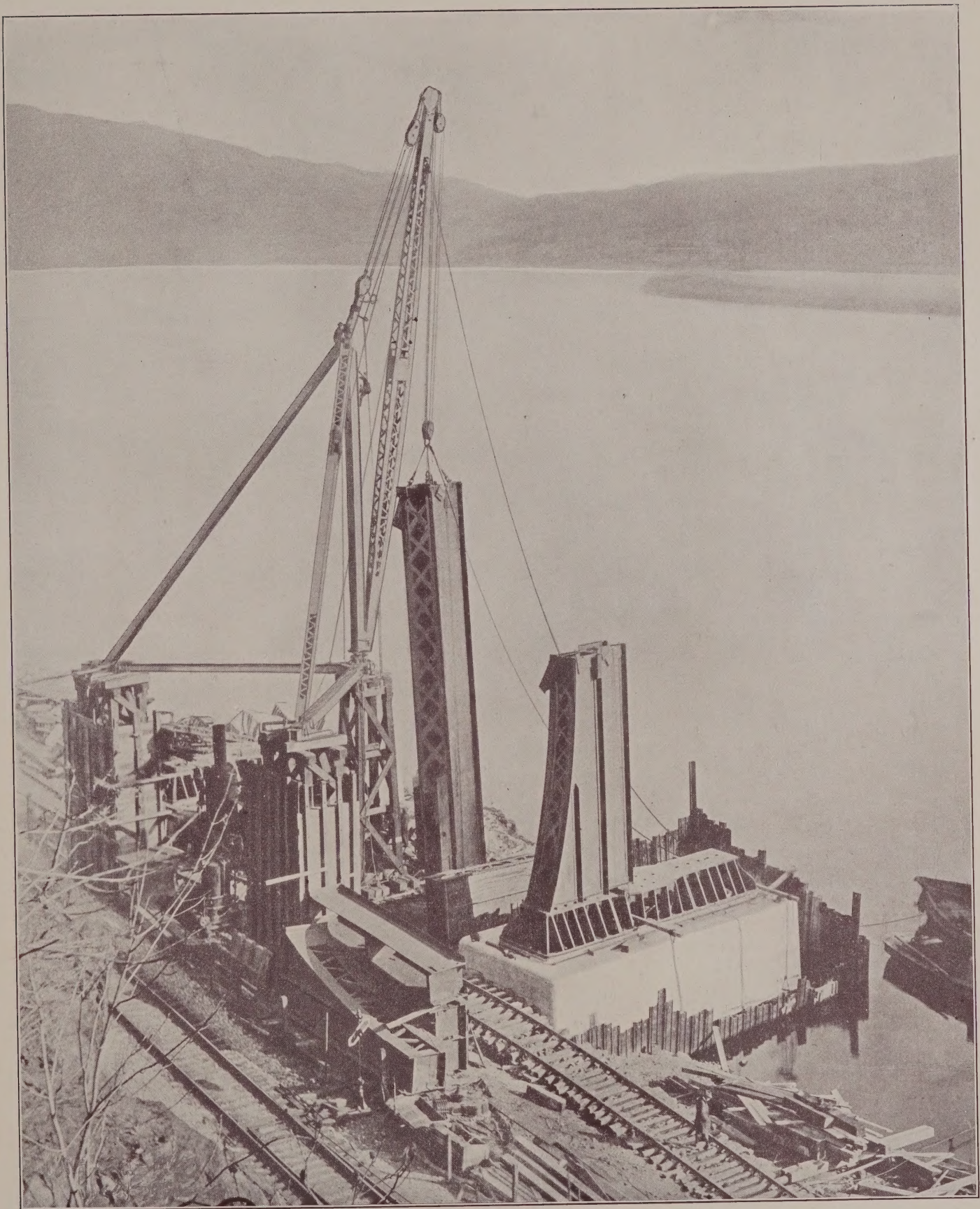


PLATE No. 1—The pier foundations are in place and the photograph shows the lower section of the northwest tower being placed upon the steel casting footing. These footings distribute the load evenly on the concrete piers.



PLATE No. 2—Taken from the top of the west tower showing excavation for anchorage pits. The larger building at the right and to the rear of the anchorage pits is the workmen's bunk house with foremen's quarters close by. The building at the left center is the field office.

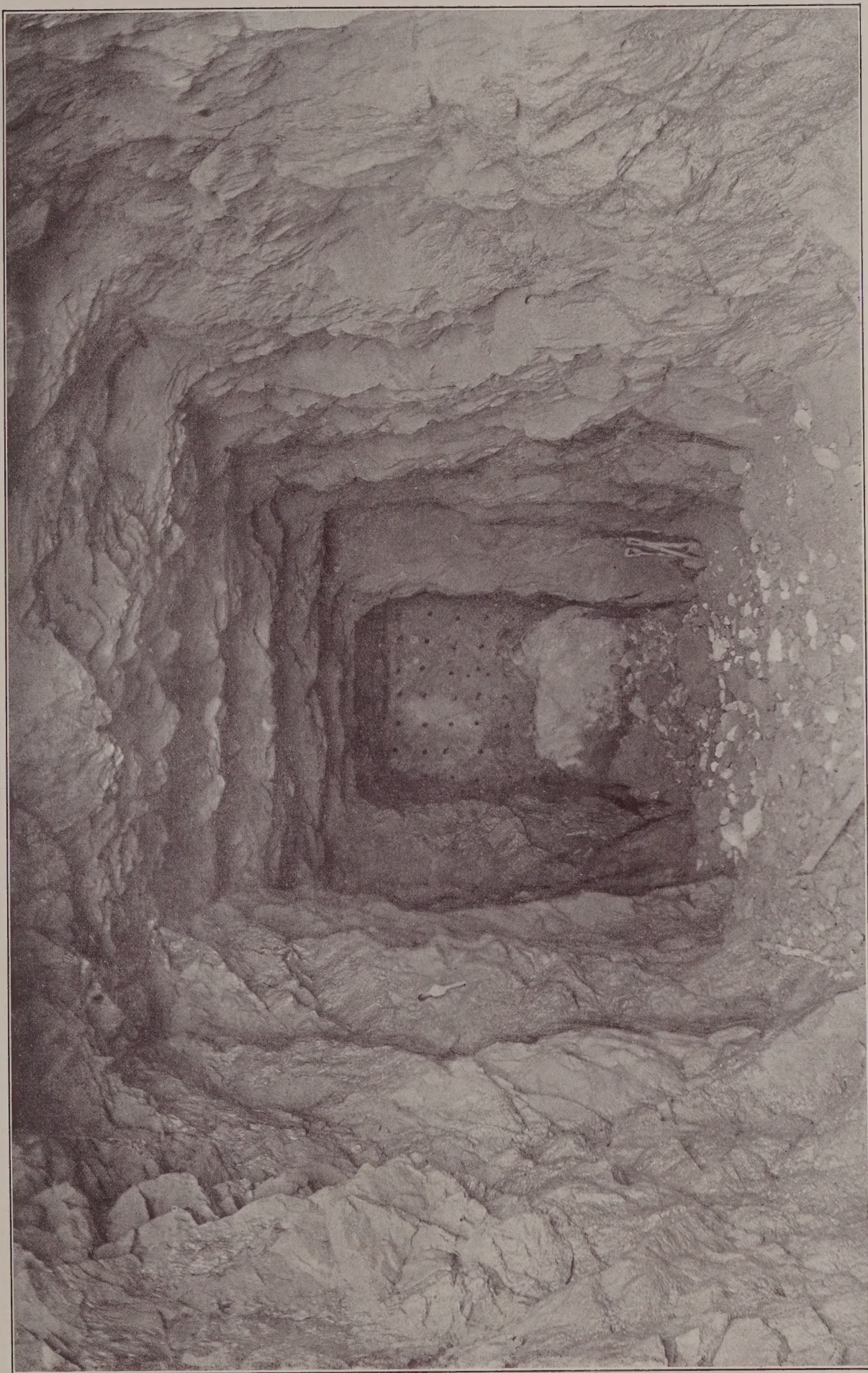


PLATE No. 3—The solid structure of the rock in which the cable anchorages are imbedded is shown by this interior view taken in one of the rock chambers. The successive steps of blasting have left their mark in the side walls and roof of the tunnel.

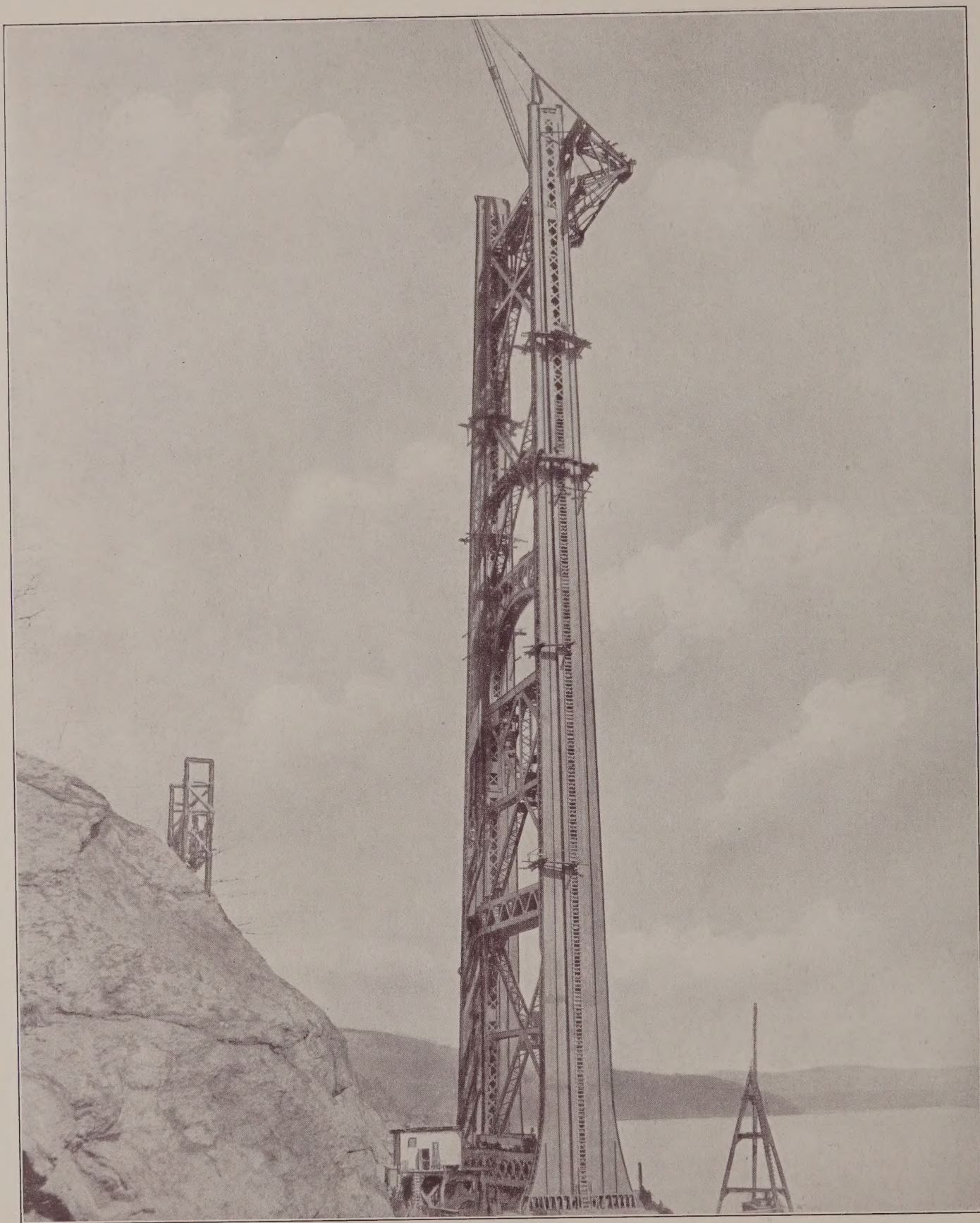


PLATE No. 4—One of the towers nearly completed. Note the creeper derrick which moves up the columns as the structure increases in height.

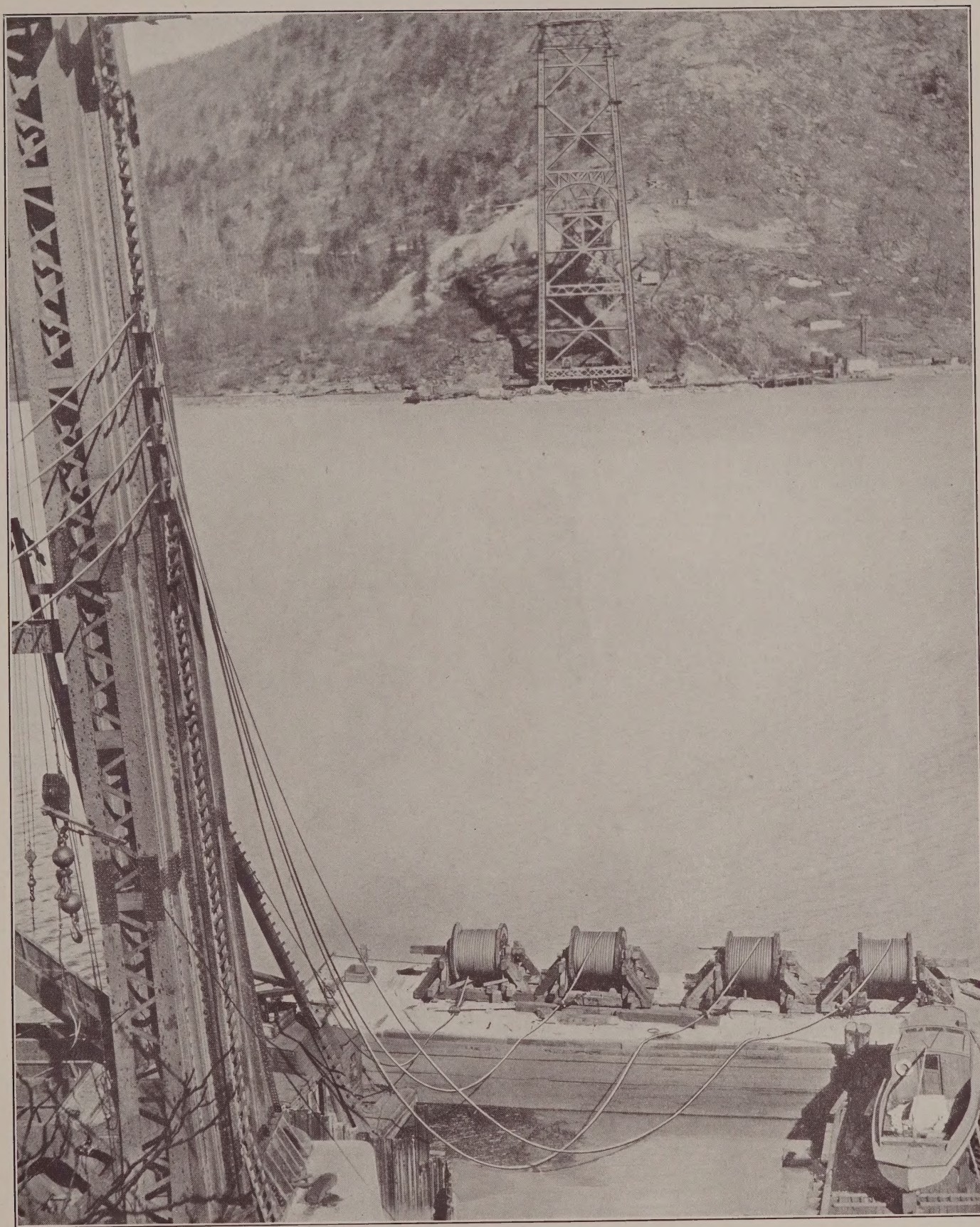


PLATE No. 5—The foot bridge ropes ready to be towed across the river. These ropes form the first connecting link between the two towers and will support the workmen's platform.



PLATE No. 6—The foot bridge ropes erected to proper deflection, awaiting the construction of the timber platform. These ropes are $2\frac{1}{4}$ -inch galvanized suspender ropes which will later be cut into multiple lengths and used as suspenders. It is very important that these ropes be erected to proper deflection as any deviation would cause difficulties in the spinning of the cables.



PLATE No. 7—Showing the construction of foot bridges partly completed. These walks are framed in sections and hoisted to the top of the towers. From this point they are slid down the ropes to their respective positions. An erection gang is shown sliding one of the sections down from the top of the near tower. This work requires great skill and daring on the part of the bridgemen.



PLATE No. 8.—The foot bridges practically completed and the tramway towers beginning to appear. There may also be seen the cross bridges in the main span which connect the north and south walks.



PLATE No. 9.—Reels of Roebling bridge wire, each containing approximately 85,000 feet in continuous length. The wire is drawn in about 3500 foot coils and these coils are joined by sleeves which are practically small turnbuckles, having right and left hand threads (see insert at top of page.)

The corresponding ends of the coils have rolled threads to fit the sleeves and the ends of the wire are beveled so as to form a lock when they meet at the center of the sleeve. In order that the wire in each strand may be in one continuous length, these reels are fastened together during construction in a similar manner.



PLATE No. 10.—The adjustment of the guide wires preparatory to spinning the first set of strands. It is very important that this adjustment be made with extreme accuracy, as it determines the length of the completed cable.



PLATE No. 11—Four strands are spun at one time. These strands are Nos. 1, 2, 3 and 4 (from left to right on each walk), No. 1 and No. 4 are spun from west to east and No. 2 and No. 3 from east to west. The incoming wheel in this picture is bringing a loop of wire for strand No. 1. The tramway is operated by an endless traction rope from a traveling sheave attached at each end of the bridge, so that when one sheave is leaving the west anchorage with a loop of wire, another is leaving the east anchorage traveling west. As there are 196 wires in each strand and as each trip of the wheel brings over a loop of wire, it requires 98 trips of the wheel for each strand.

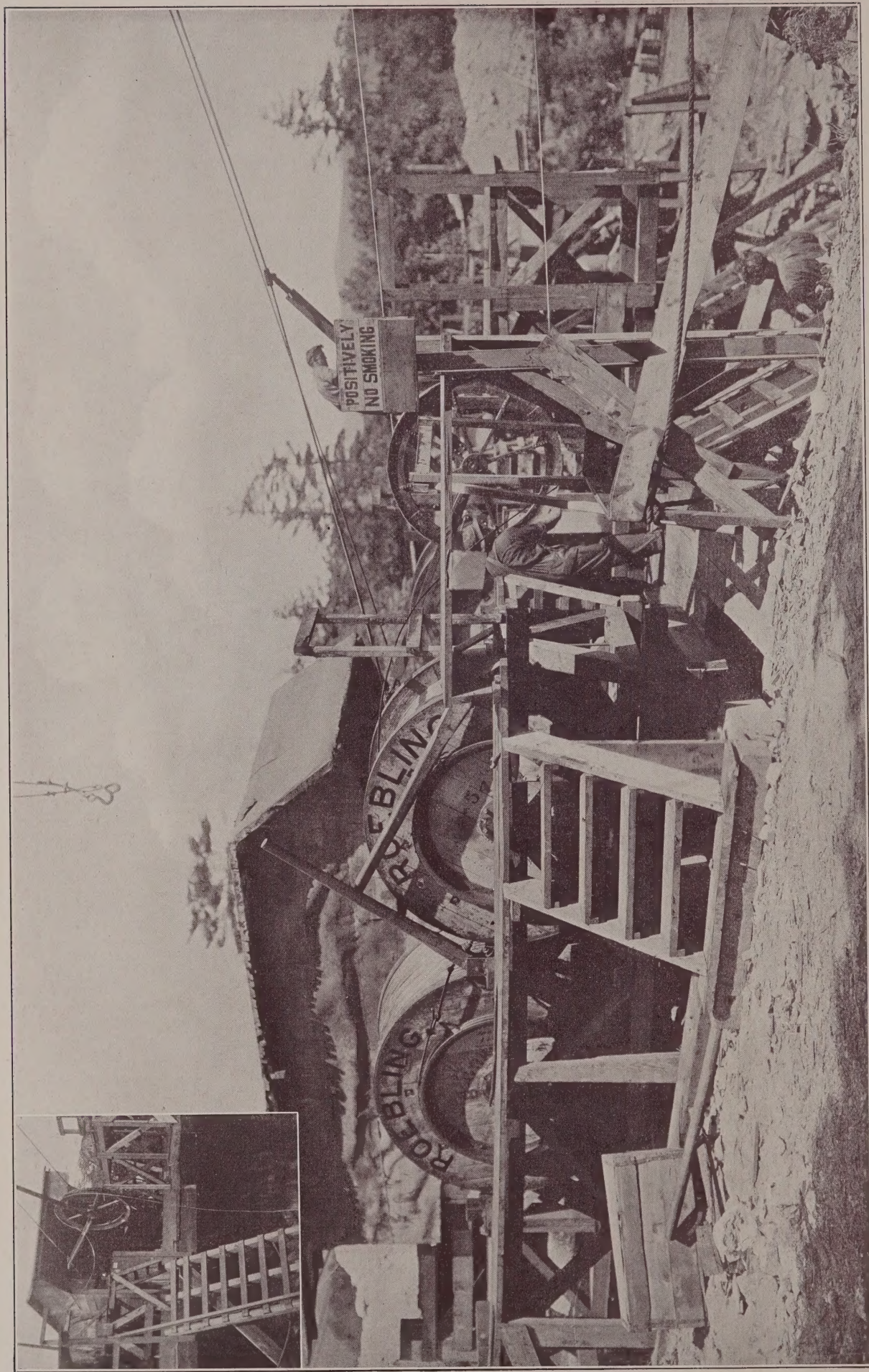


PLATE No. 12.—A view of the southwest anchorage. The wheel has just come in on No. 4 strand, and the anchorage foreman can be seen waiting for a little slack so that he can remove the loop of wire from the wheel. The anchorage man is shown in the right foreground waiting to receive the loop of wire and pass it around No. 4 strand shoe where it will be adjusted to its proper deflection in the strand. After No. 4 loop is removed from the wheel, a new loop is formed from No. 3 reel and the wheels are again pulled across the river. The workman standing back of the "No Smoking" sign is the brakeman tending the brakes on No. 2 reel. As the wheels start their next trip, he will cross over to the near side to control the brakes on No. 3 reels.

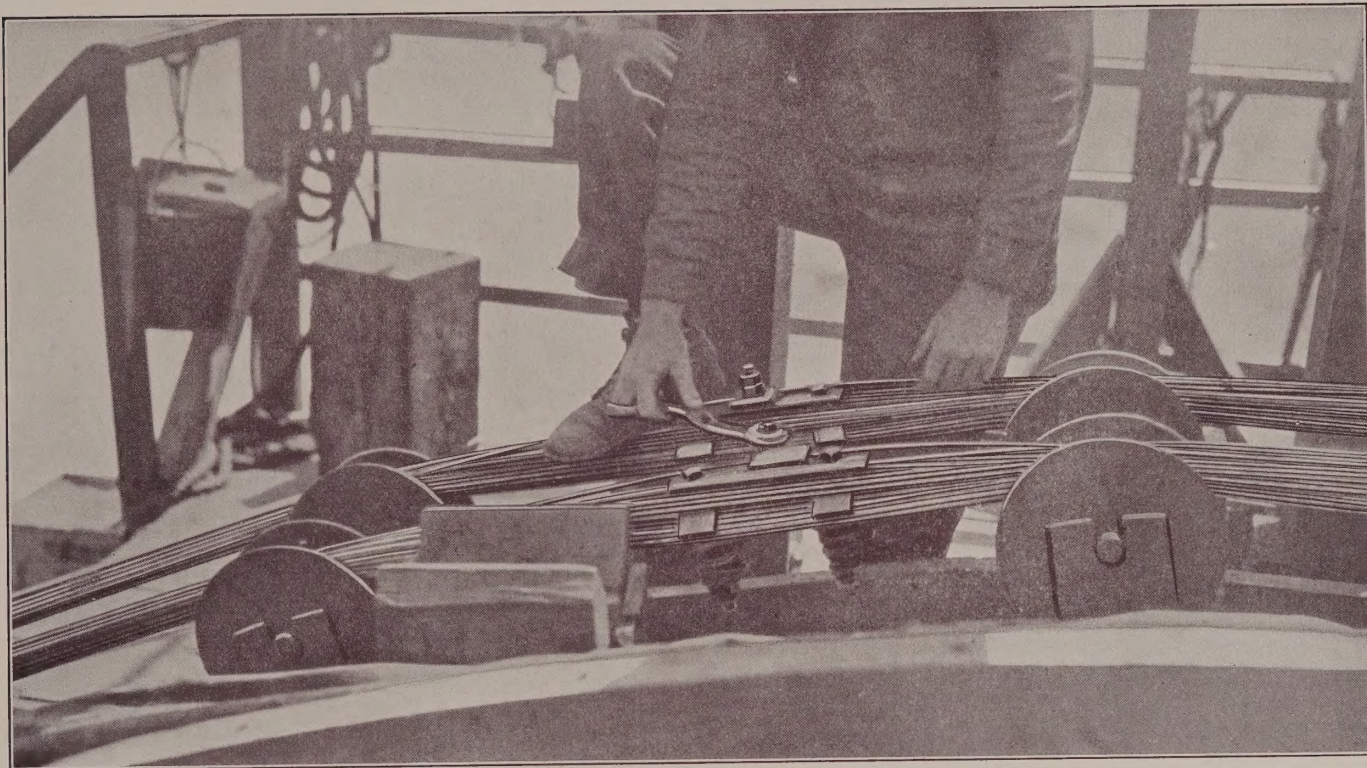
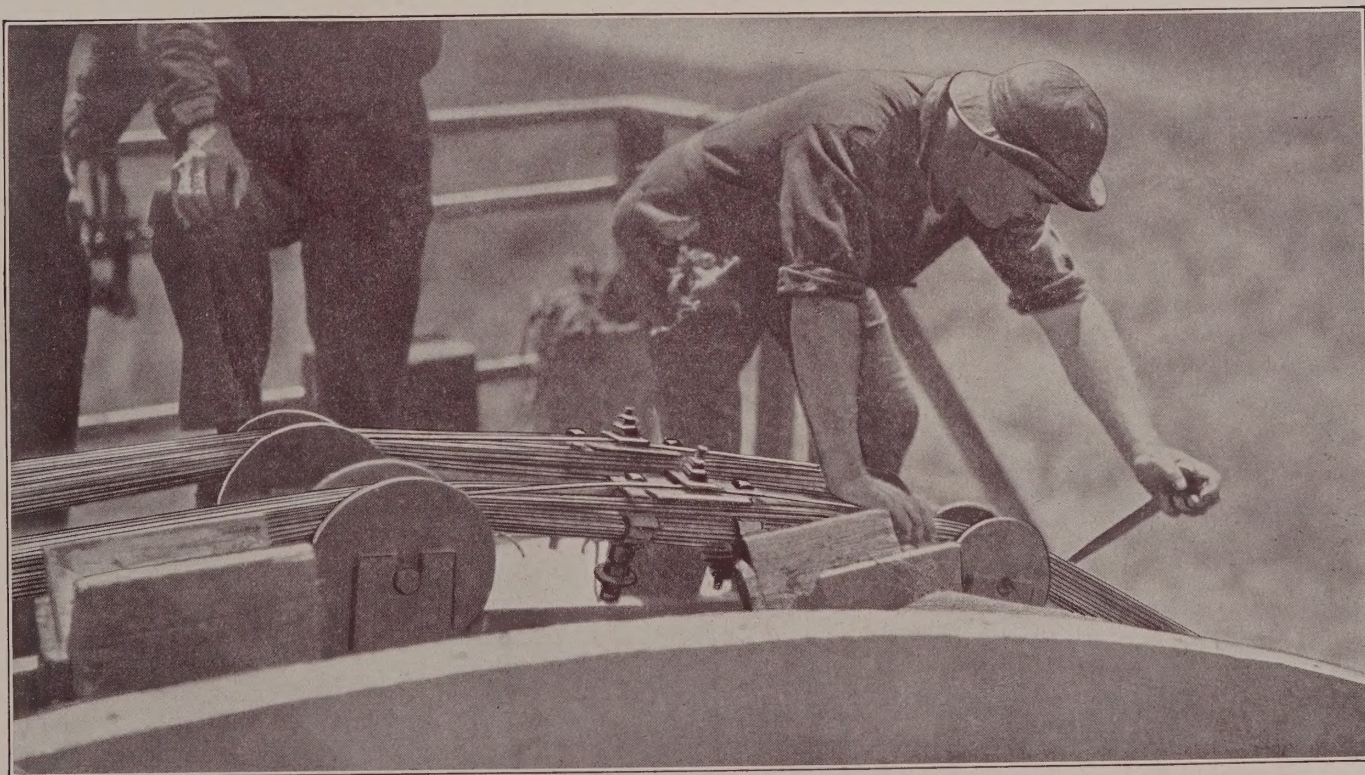


PLATE No. 13.



PLATES No. 13 and No. 14—In order to hold the newly spun wires in adjustment in the spans until they are permanently clamped around the anchorage shoes, it is necessary to use special tower clamps, as shown in the above pictures. Each wire as it is being adjusted, is held in these clamps until the approach of the next trip, when it is removed from the central clamp and slipped over to one side. There are two clamps at each tower for each strand.



PLATE No. 15.—Adjustment of wires in the anchorages. The workman in the foreground is pulling the wire into adjustment, taking his signals from the flagman in the middle of the land span walk (see insert). The workman at the left is attending the clamp at the strand shoe ready to permanently clamp the wire into its final position when given the "O. K." by the flagman.

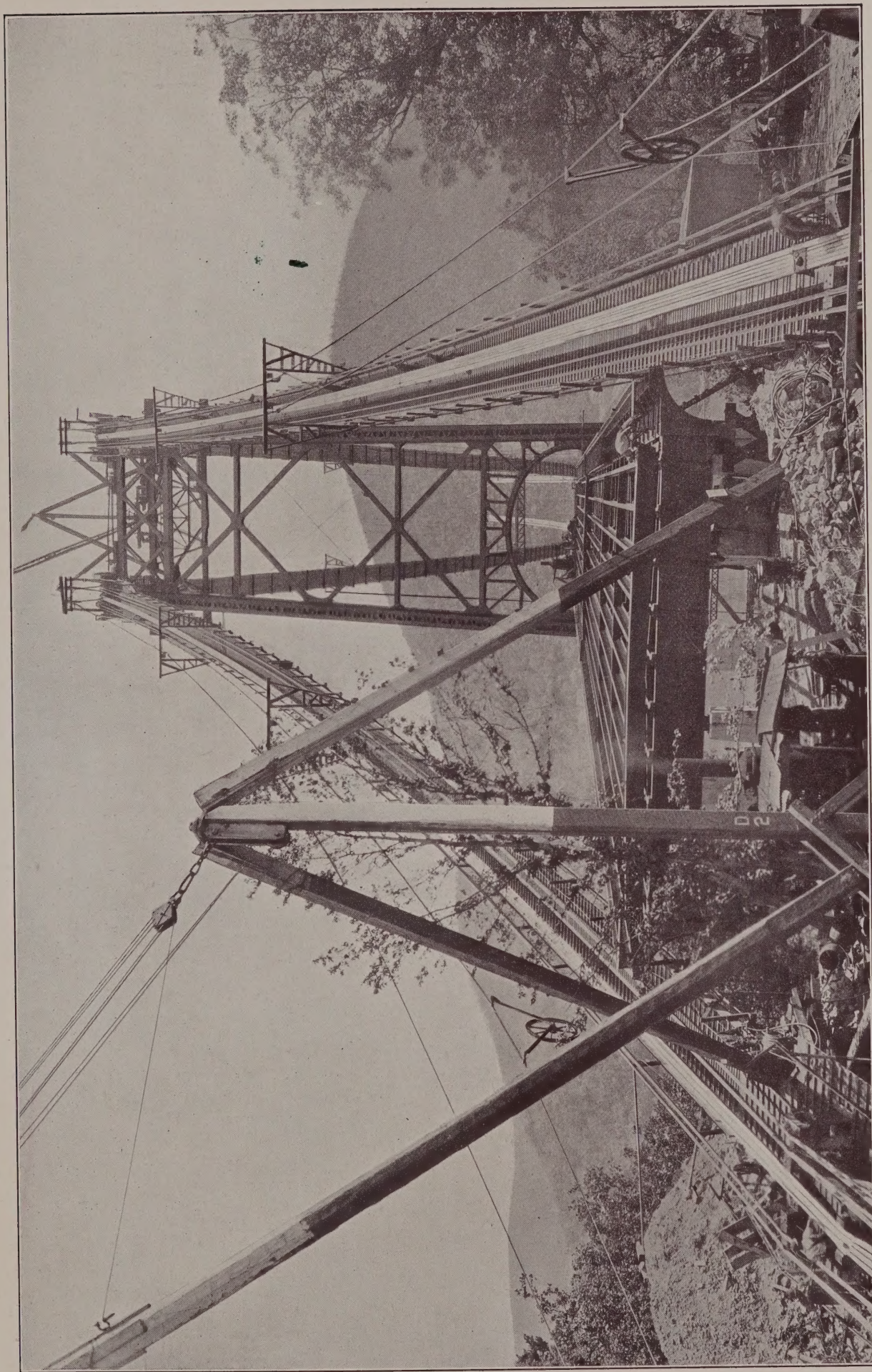


PLATE No. 16 —A typical view of cable construction on south walk (right). The loop of wire having been placed over the wheel (lower right), it is now ready to start back on No. 3 strand. The semaphore arm is "up" on the southwest tower indicating that the workmen are adjusting No. 4 live wire in the land span. The flagman can be seen giving signals on this wire about half way up the walk.

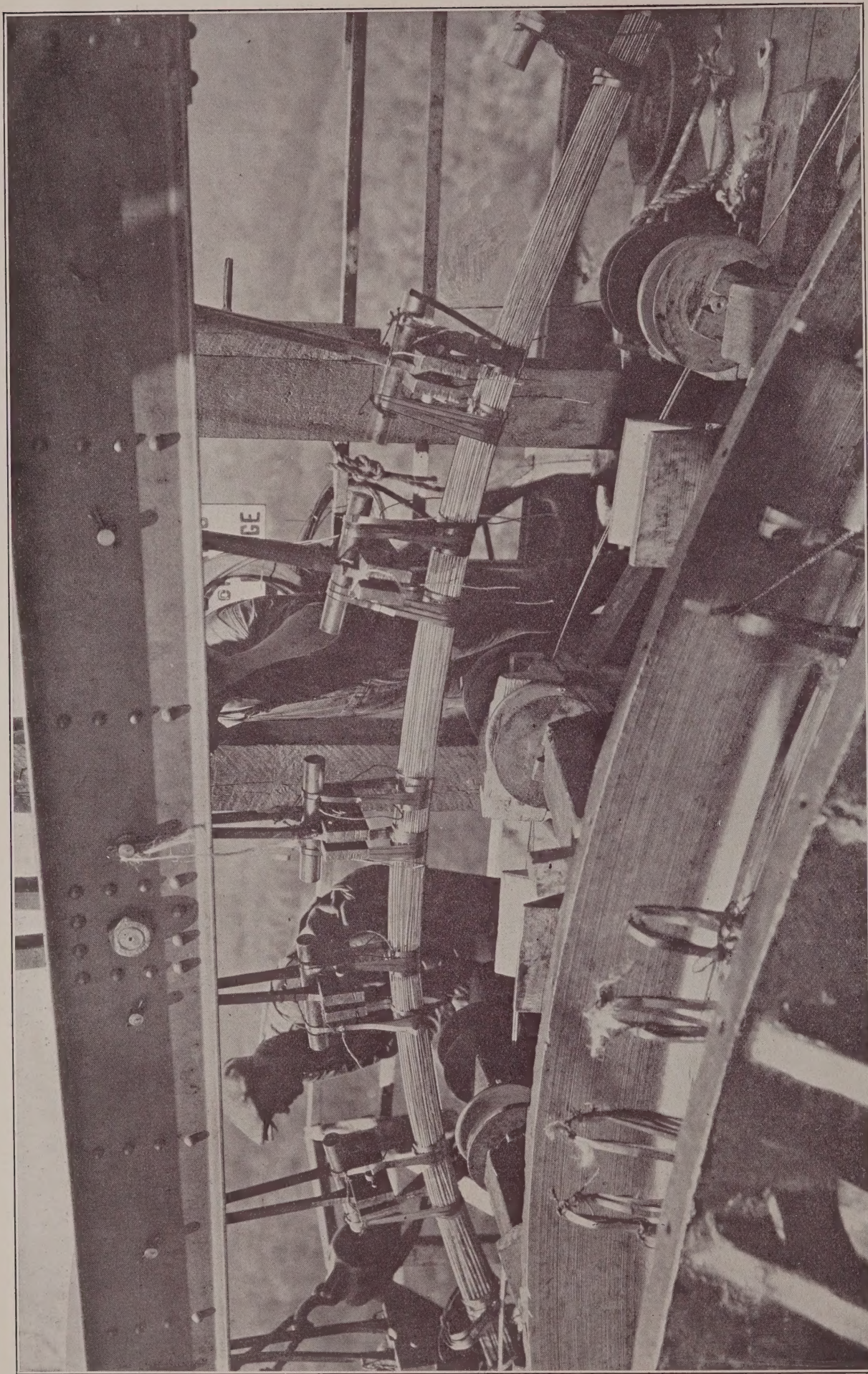


PLATE No. 17—As each strand is completed, it is compacted in circular section by means of special tongs and held in place by bands or servings of steel flat wire. It is then necessary to lift the finished strand into its proper place in the saddle for adjustment. It will be observed that the strand is fastened to the equalizing beam by means of flat wire wrappings. This equalizing beam prevents the strand from being "kinked" while suspended in the air.



PLATE No. 18—Another group of strands has been completed and the two halves are being squeezed together near the strand shoes to receive permanent wire servings.

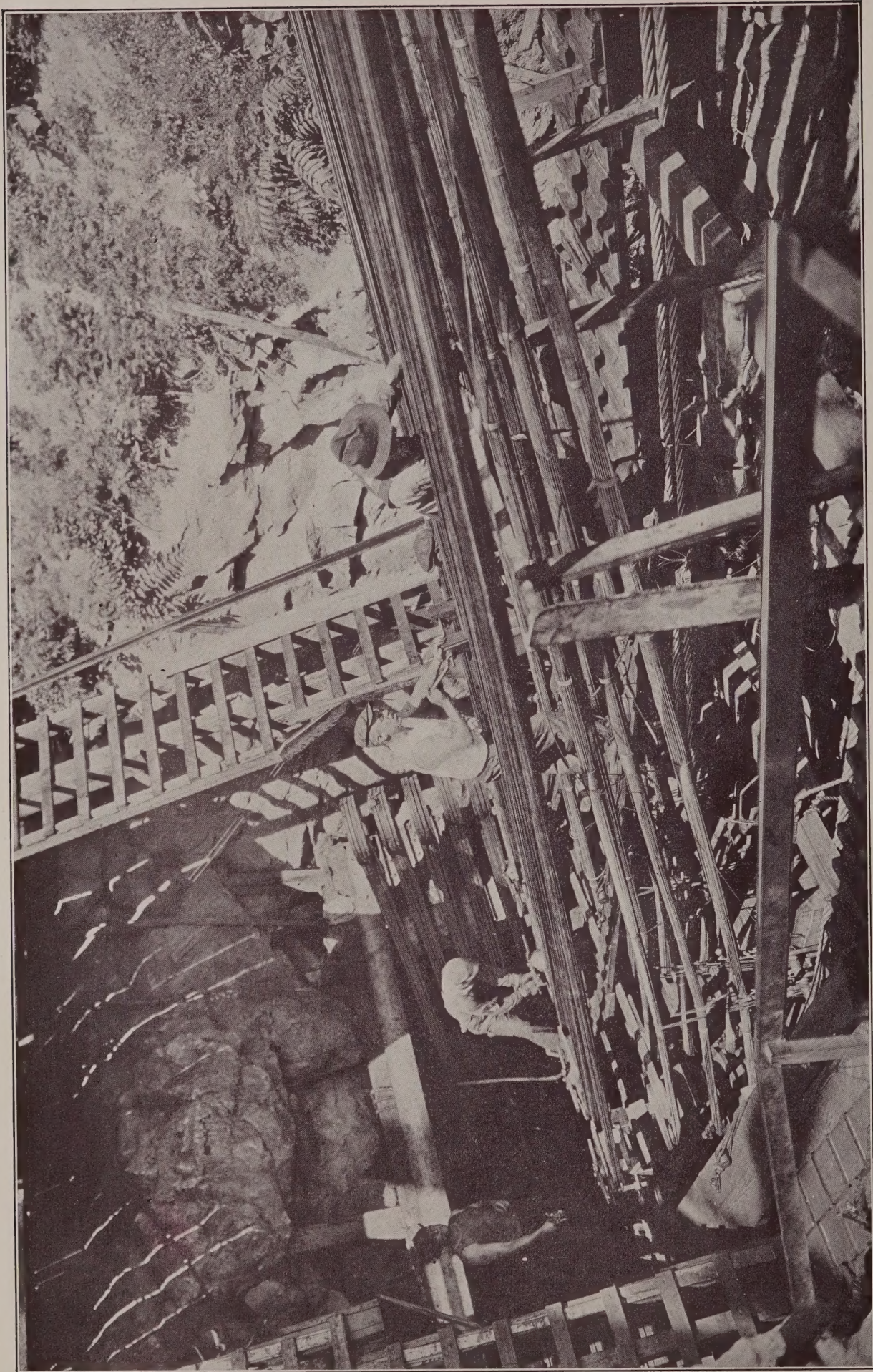


PLATE No. 19—Another view of the operation described under Plate No. 18.
Note the temporary position of the strand shoes above the eyebars while spinning.

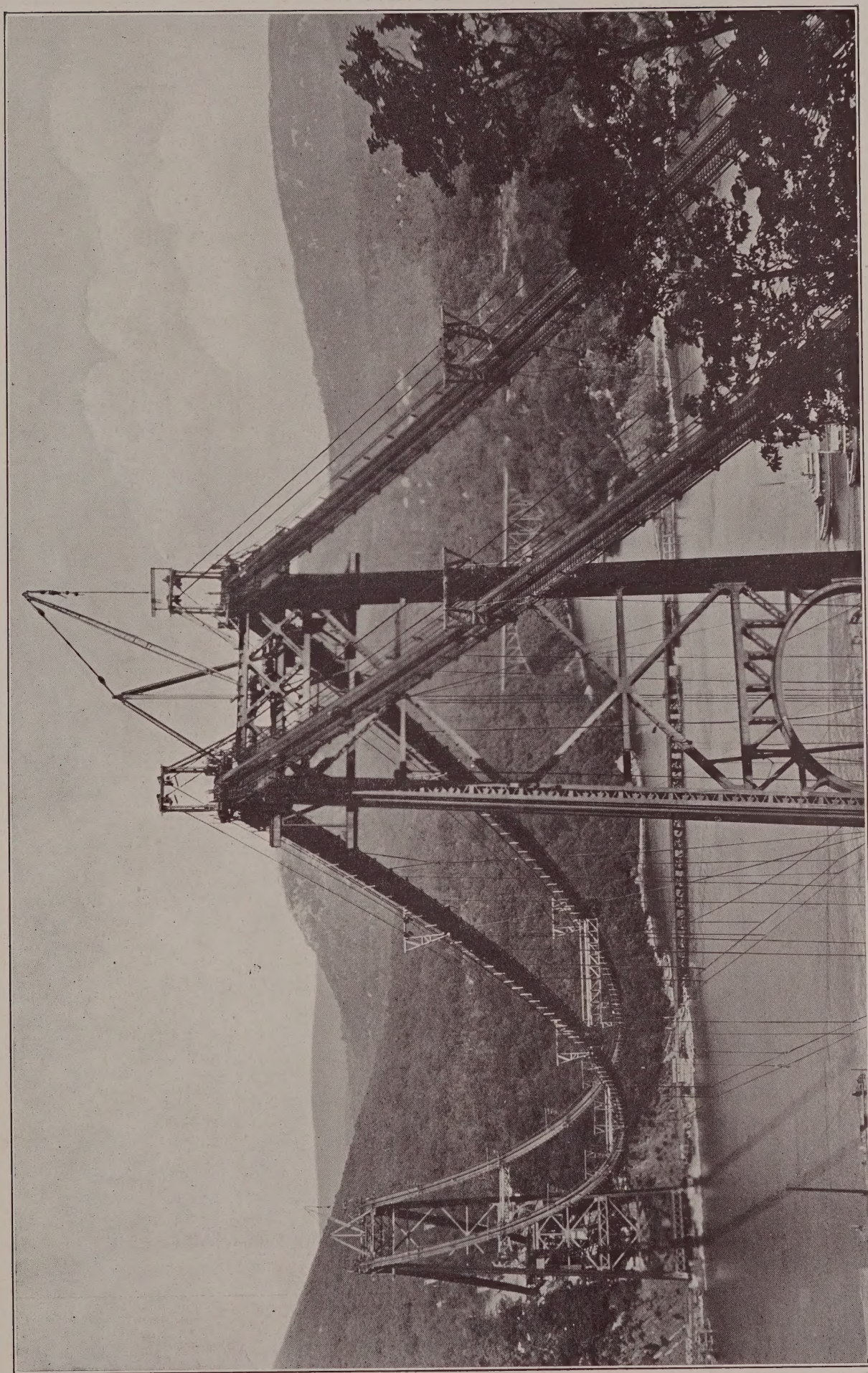


PLATE No. 20.—A general view of the foot walks during the spinning of the cables. The strands of the north walk have just been completed.



PLATE No. 21—Looking east from the top of the west tower. On the south walk (right) workmen are seen tying in the newly spun wires. On the north walk banding gangs are at work putting the flat wire bands on finished strands.

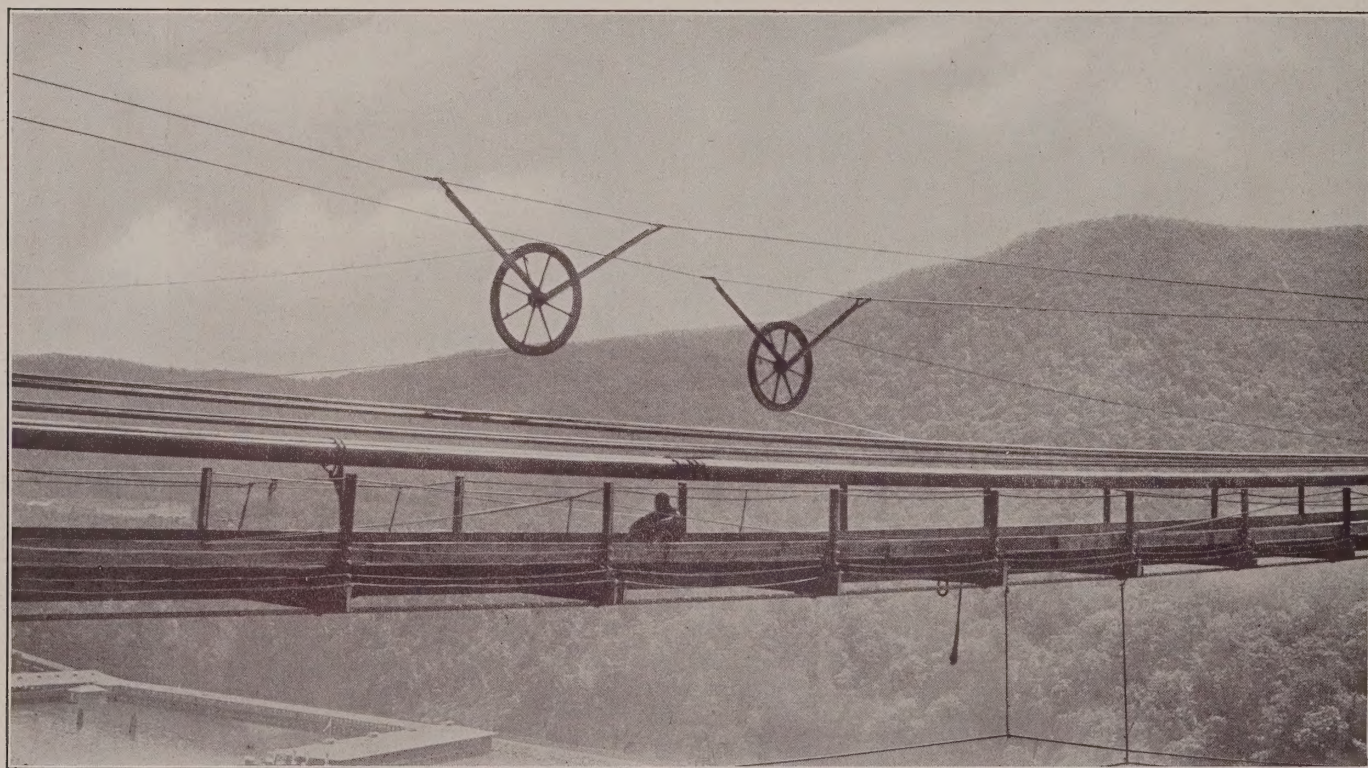


PLATE No. 22—The wheels passing at the center of the span. Note the loop of wire over each wheel. The workman sitting beneath the partly finished cable is the flagman waiting for these wheels to pass over the towers after which he will give signals for the adjustment of the wires.

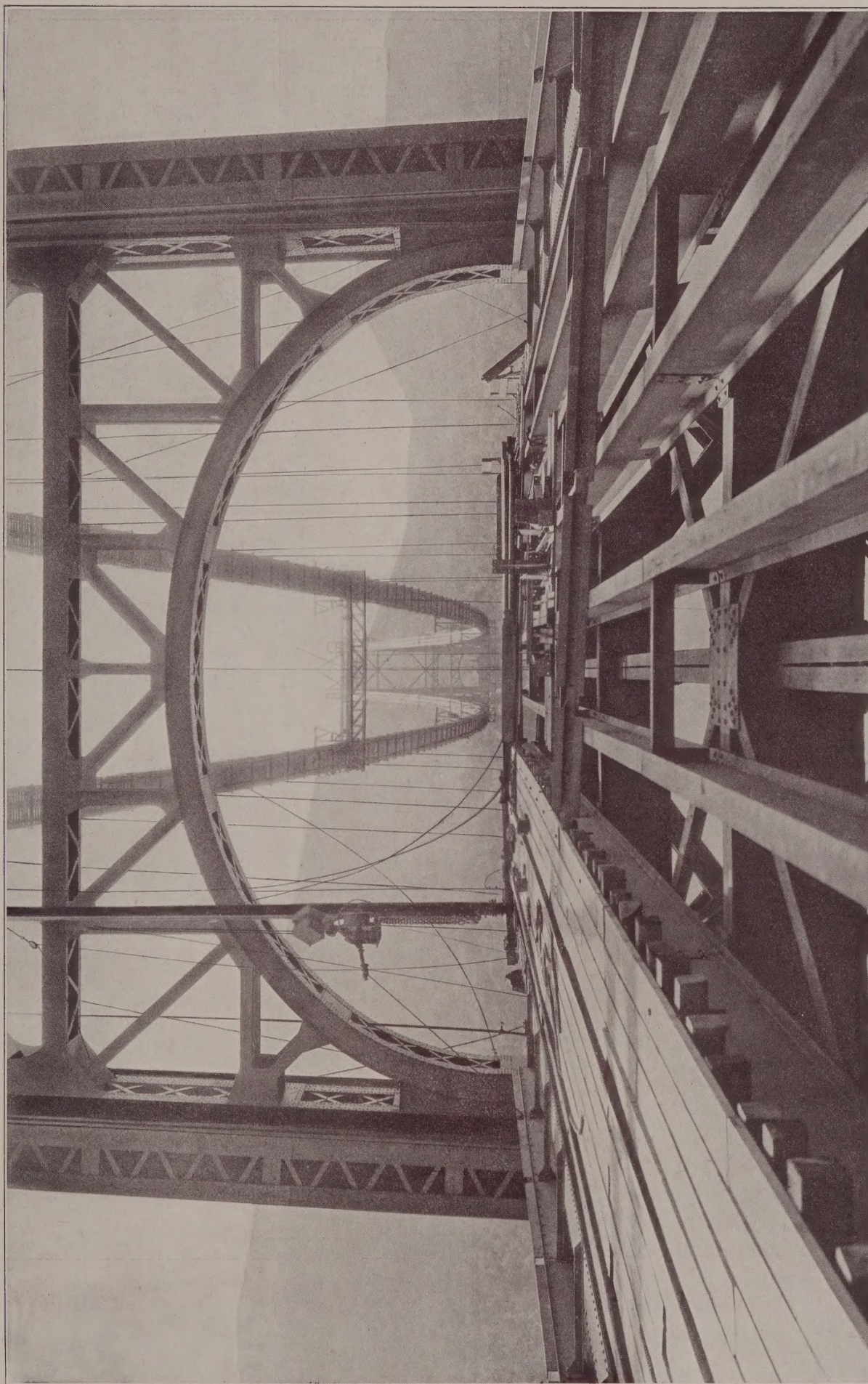


PLATE No. 23—A view taken from the east approach of the span showing the deflection of the main cables The roadway will pass under this arch.



PLATE No. 24—It will be noted that the middle or widest layer of the hexagon shape cable on the south walk has been completed, indicating that the spinning is over half finished.

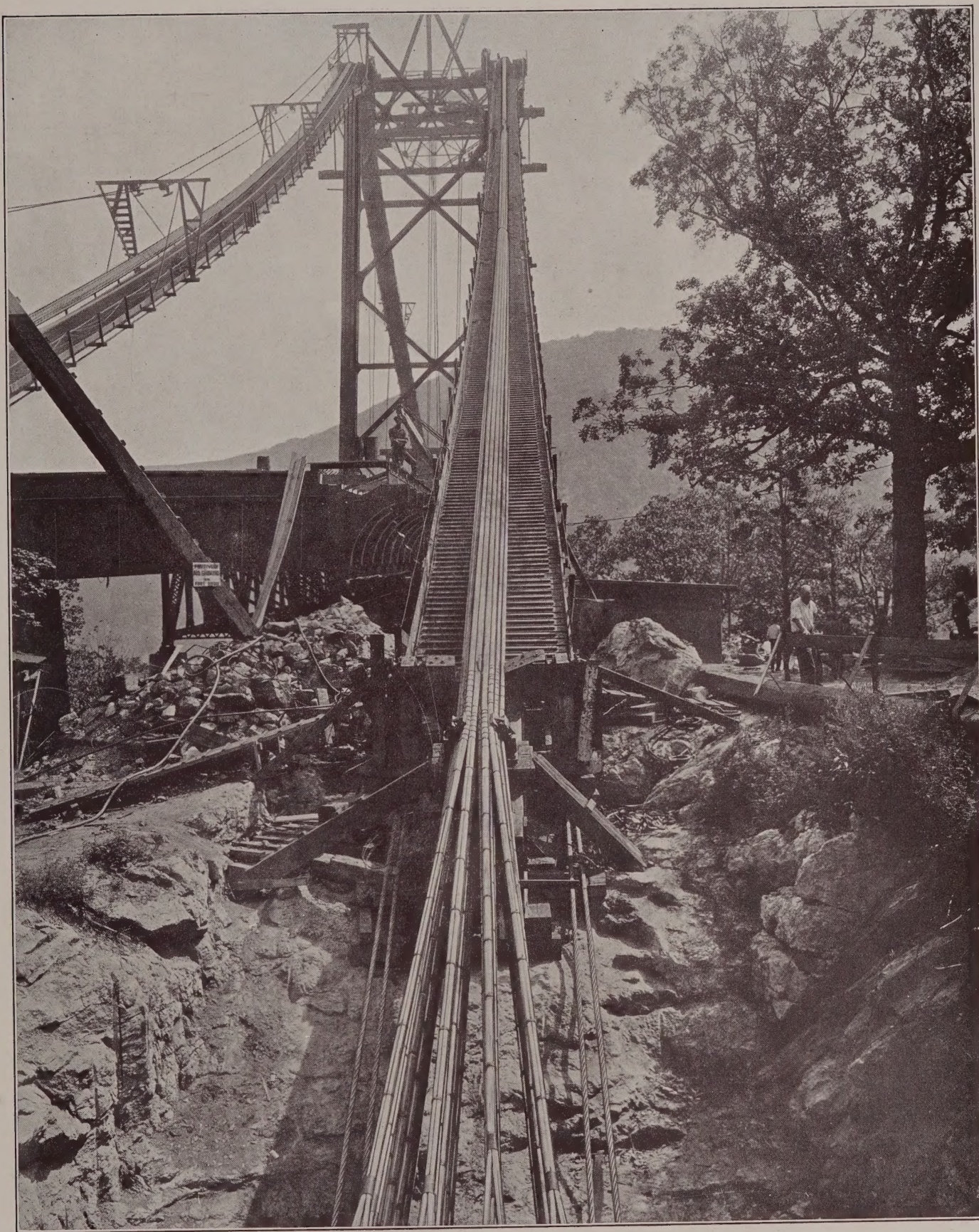


PLATE No. 25—The spinning on the south walk has been completed, while the north walk is spinning the last strand. The hexagon formation of the strands can be noted in the lower part of the cable, while the portion near the towers has been compacted. Note also that the tramway tower on the south walk has been removed.

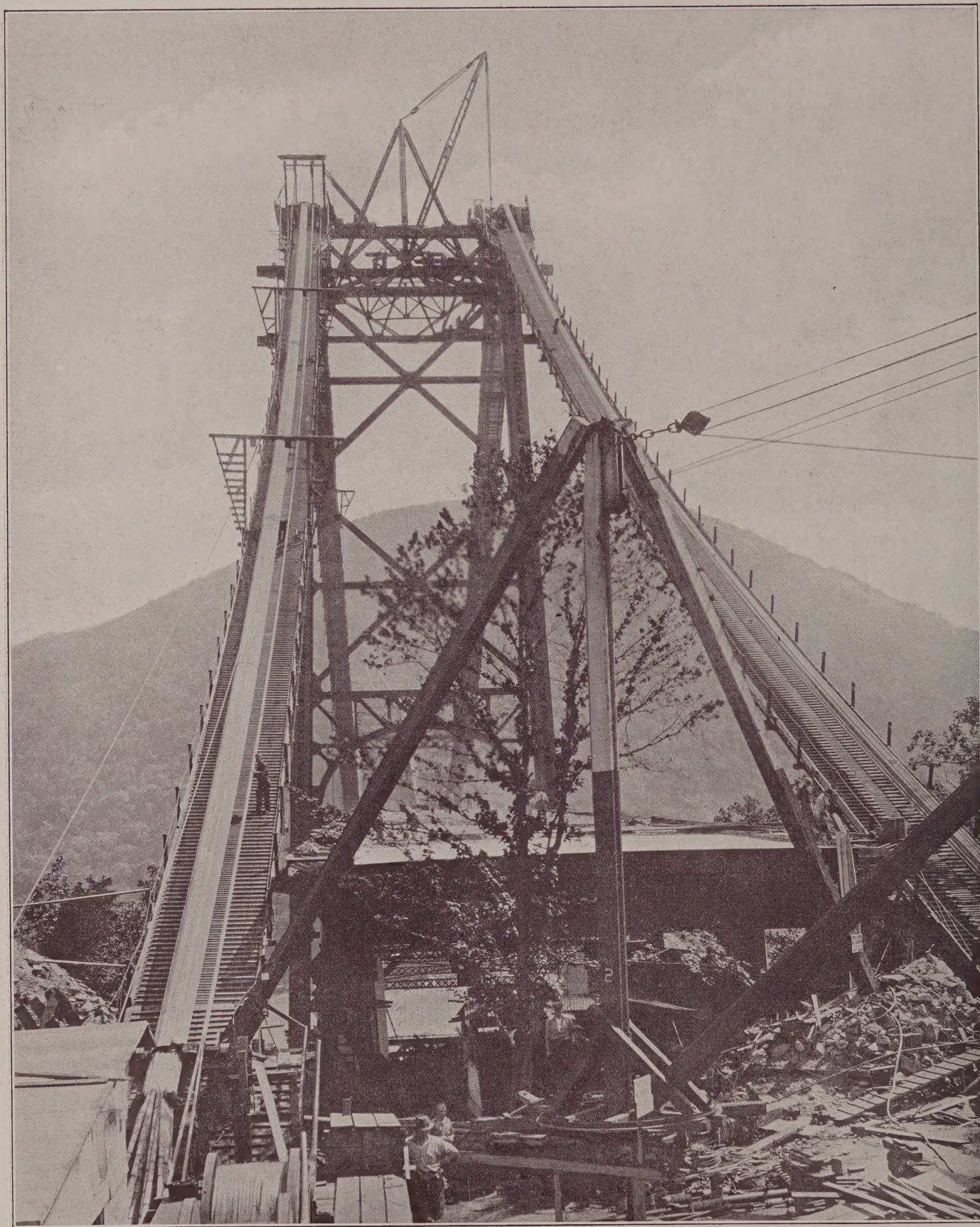


PLATE No. 26—The last wire has been spun, completing the last strand of the cables. There are 37 strands in the finished cable, and as four strands are spun at once in each group, it is necessary to spin the 37th or last strand alone.

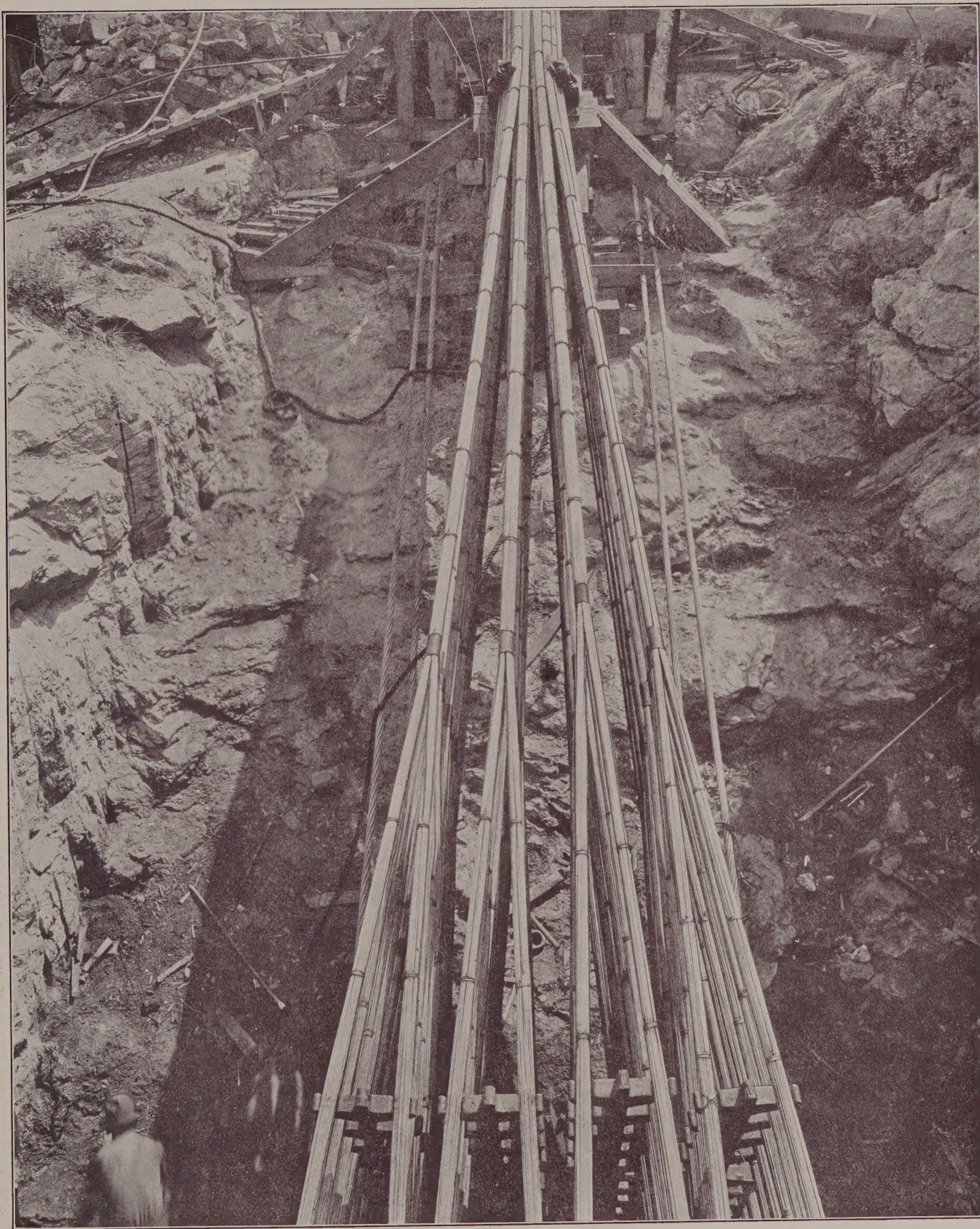


PLATE No. 27—The anatomy of one of the great supporting cables near the anchorage.

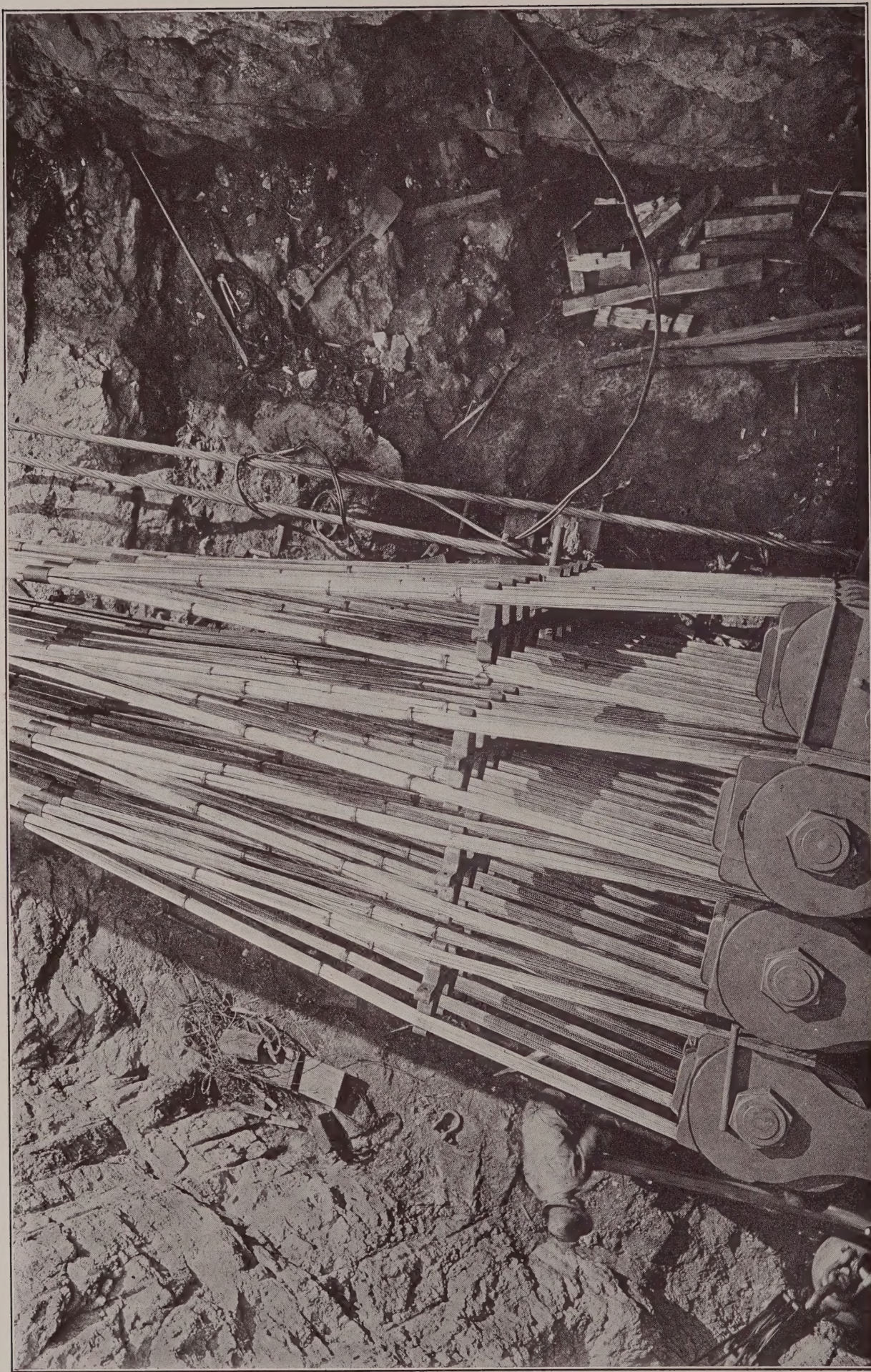


PLATE No. 28 - Note how the strand shoes are attached to the eyebar chains, which are securely anchored in solid rock. As the eyebars were placed in the horizontal position, it was necessary to use the steel casting tree separators, shown above, to prevent the wires from scrubbing against the steel shoes.



PLATE No. 29—The inside of the southwest anchorage pit, showing the formation of the eyebar chains. Note how the finished strands are attached to the anchor chains by means of the strand shoes, pin connected to the eyebars. The foot bridge ropes can be seen at the bottom of the picture leading to their anchorages.

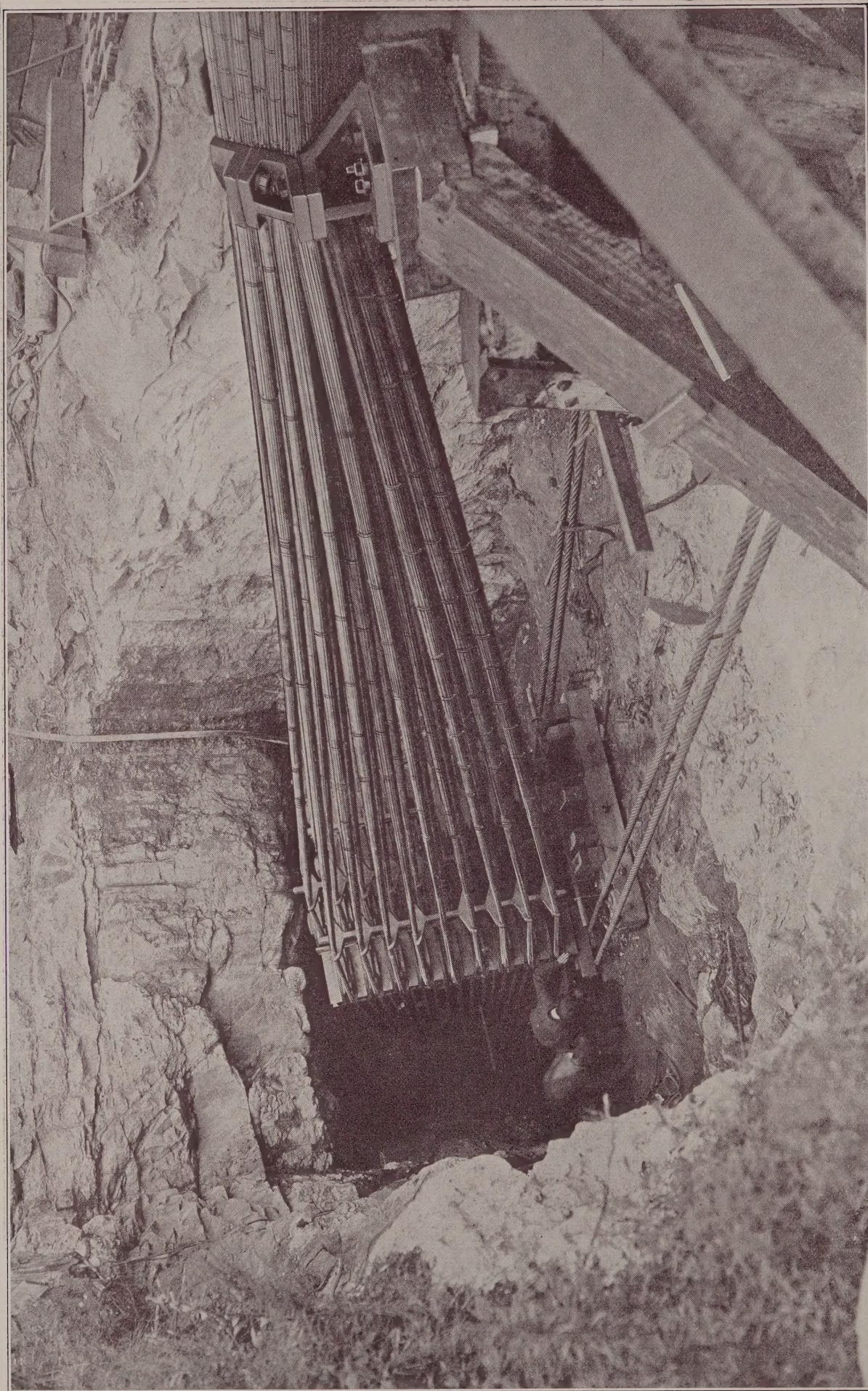


PLATE No. 30—The completed cable, 7252 wires, 37 strands, each strand transferring its part of the load to the solid rock foundation. Note the temporary throat clamp from which the individual strands diverge to their respective eyebar chains.

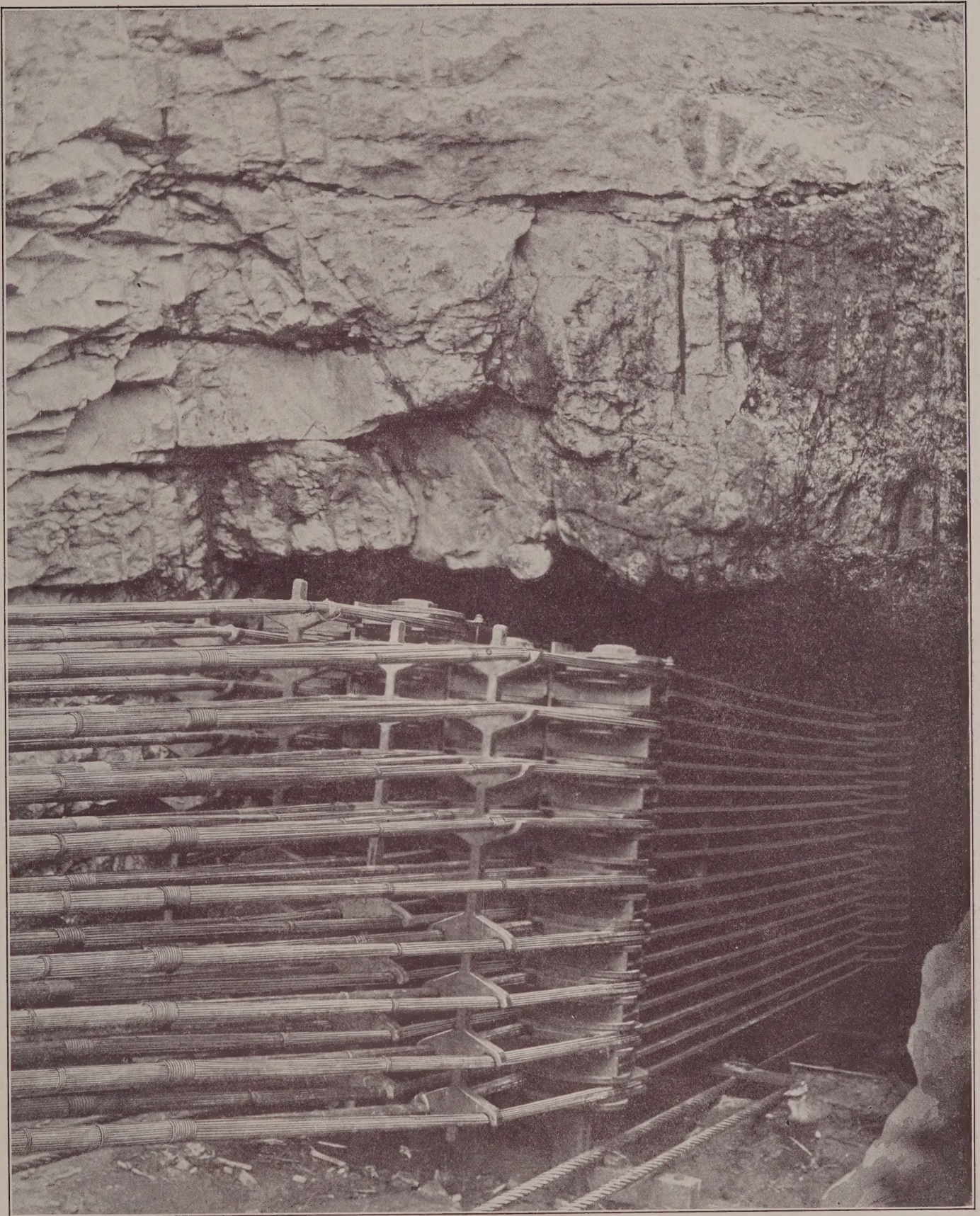


*PLATE No. 31—A “close up” of the steel casting
tree separators.*

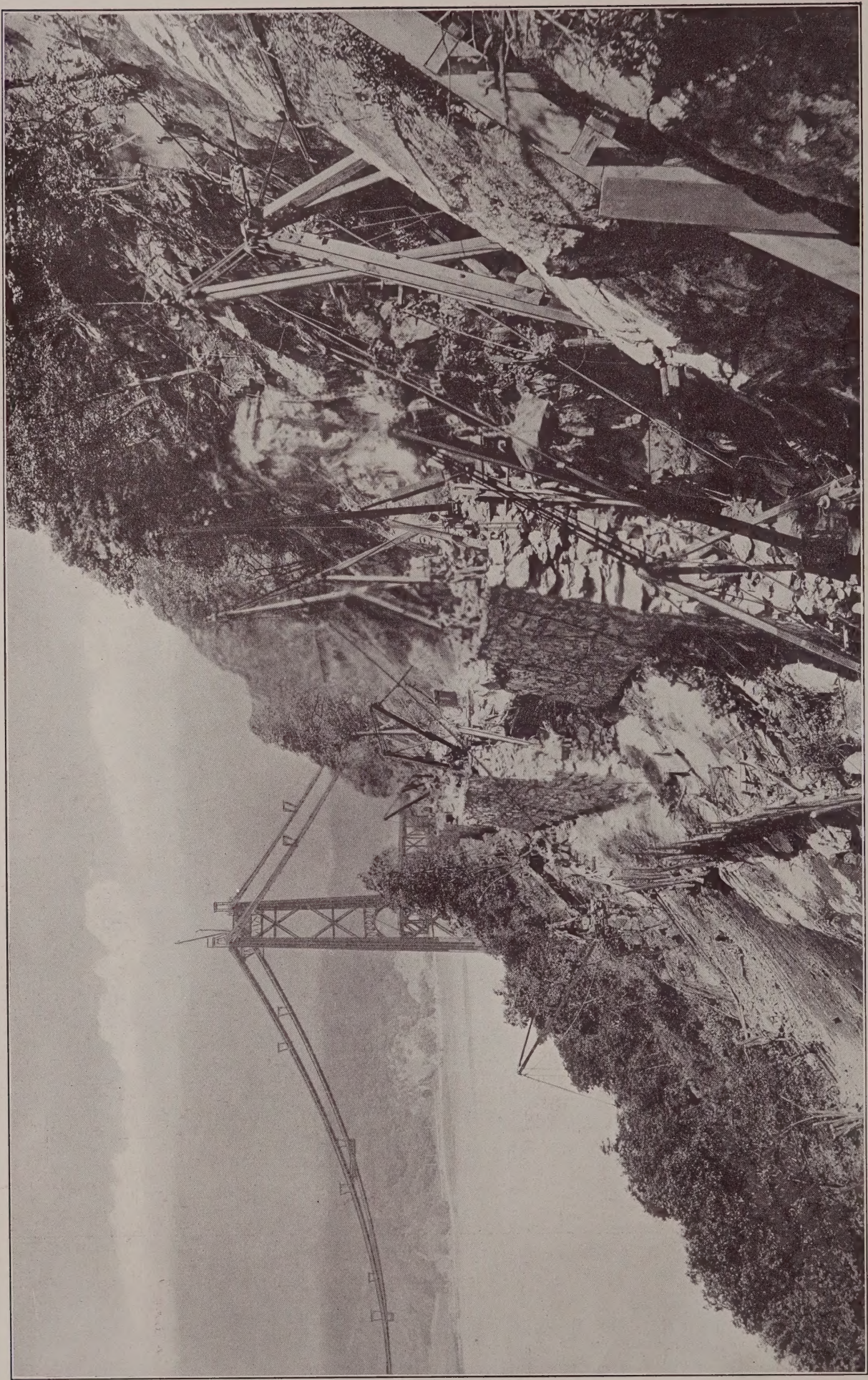


PLATE No. 32—Rugged road construction cut in the side of "Anthony's Nose."
It was necessary to build three miles of this type of roadway to provide the east approach to the bridge.

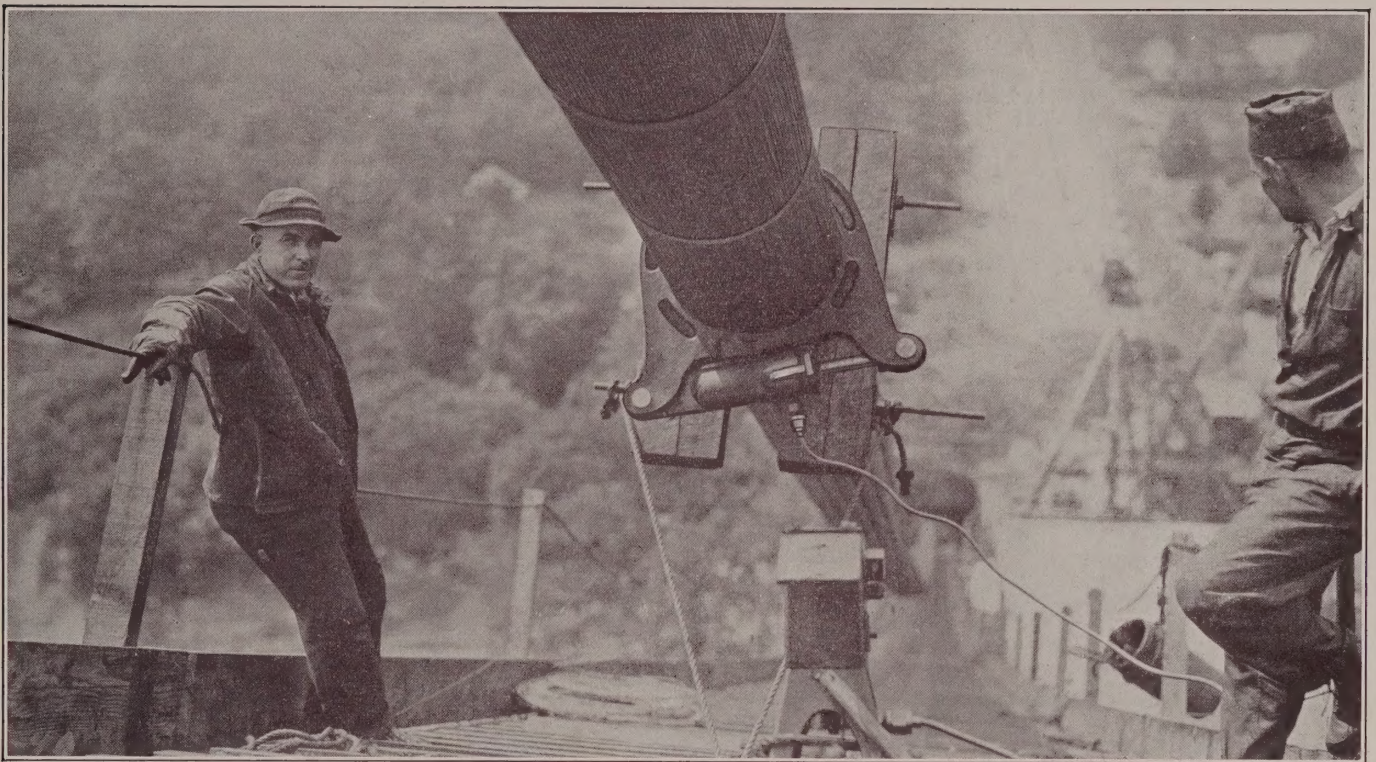


PLATE No. 33—Thirty-seven strands are compacted into a circular section 18 inches in diameter. This photograph shows the type of squeezing jack used with the hydraulic pump in the foreground. The wooden clamp back of the squeezer is to prevent the squeezer from slipping down the cable when the pressure is released. The cable is compressed at two foot intervals and a tight serving of No. 8 galvanized annealed wire is applied to keep the compacted cable in its circular section.



PLATE No. 34—One of the squeezing gangs.

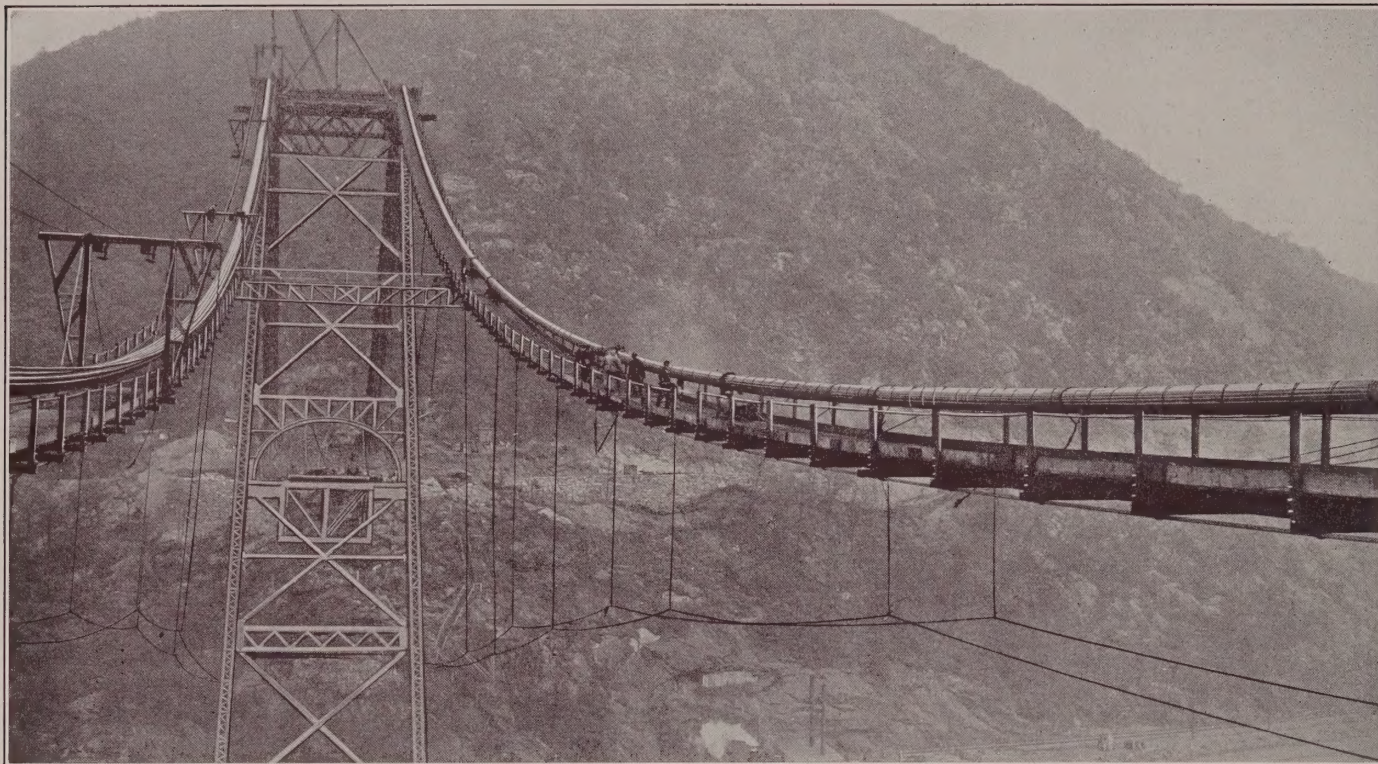


PLATE No. 35—The compacting of the south cable nearly completed. Preparations are being made to lift over and adjust the last strand on the north walk.

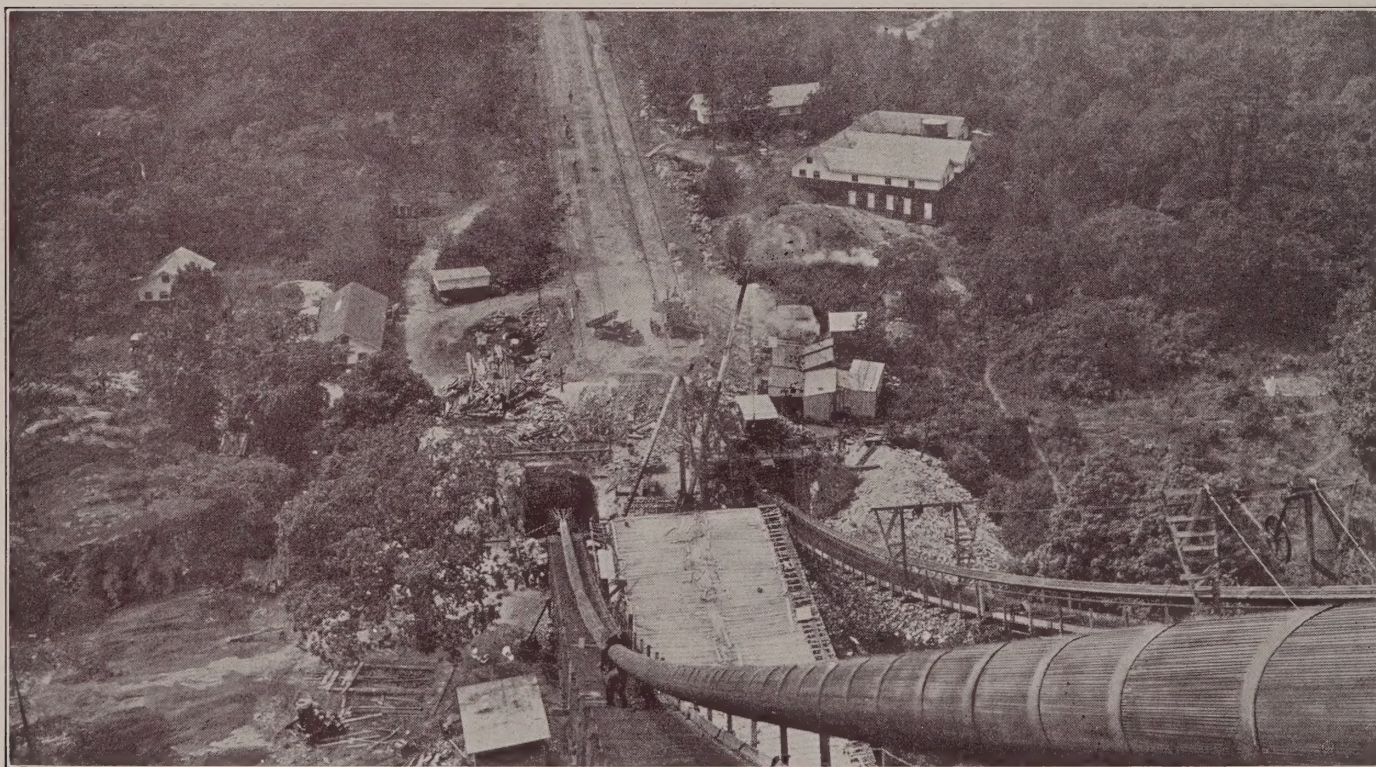


PLATE No. 36—Note the root like spreading of the strands at the anchorage.



*PLATE No. 37—Finishing the compacting of the north cable.
A squeezing gang at work.*

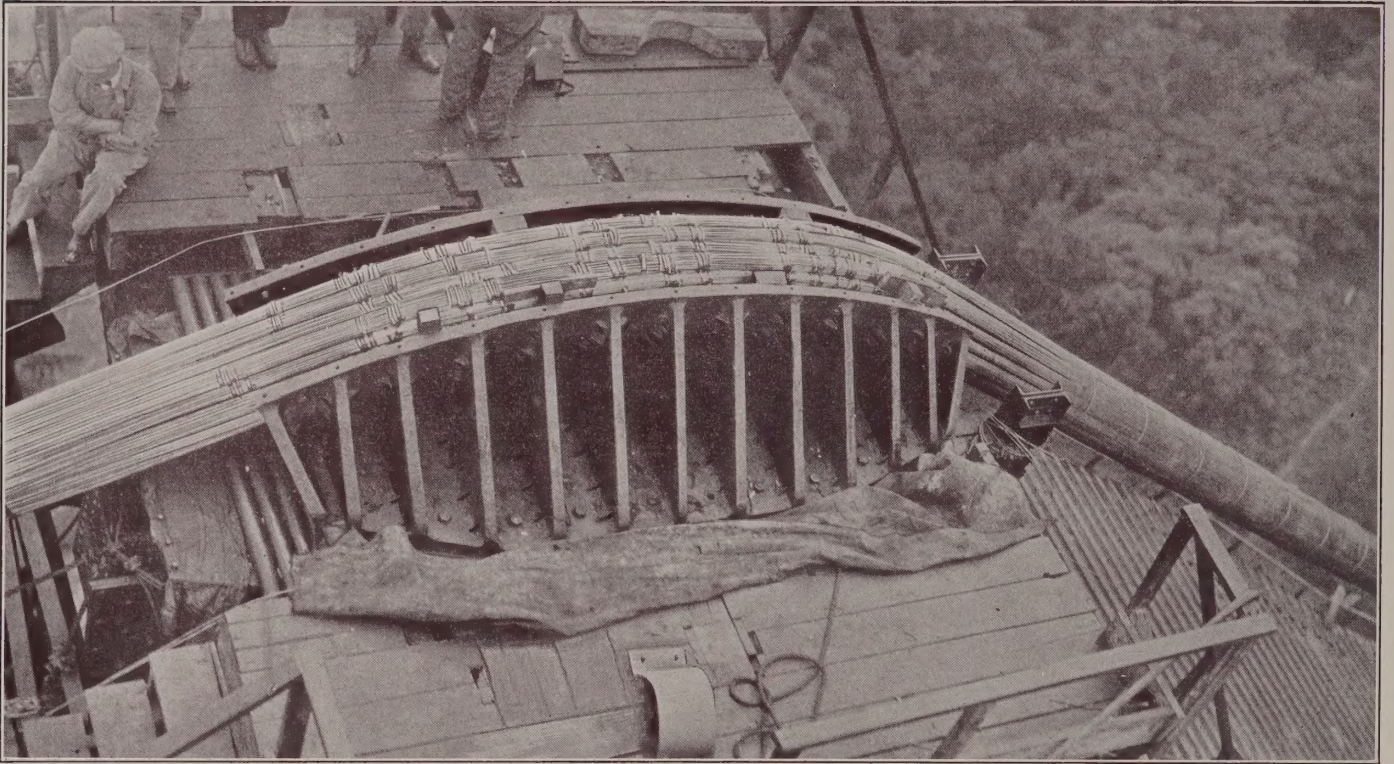


PLATE No. 38—A bird's eye view of the finished cable, passing over the tower saddles.

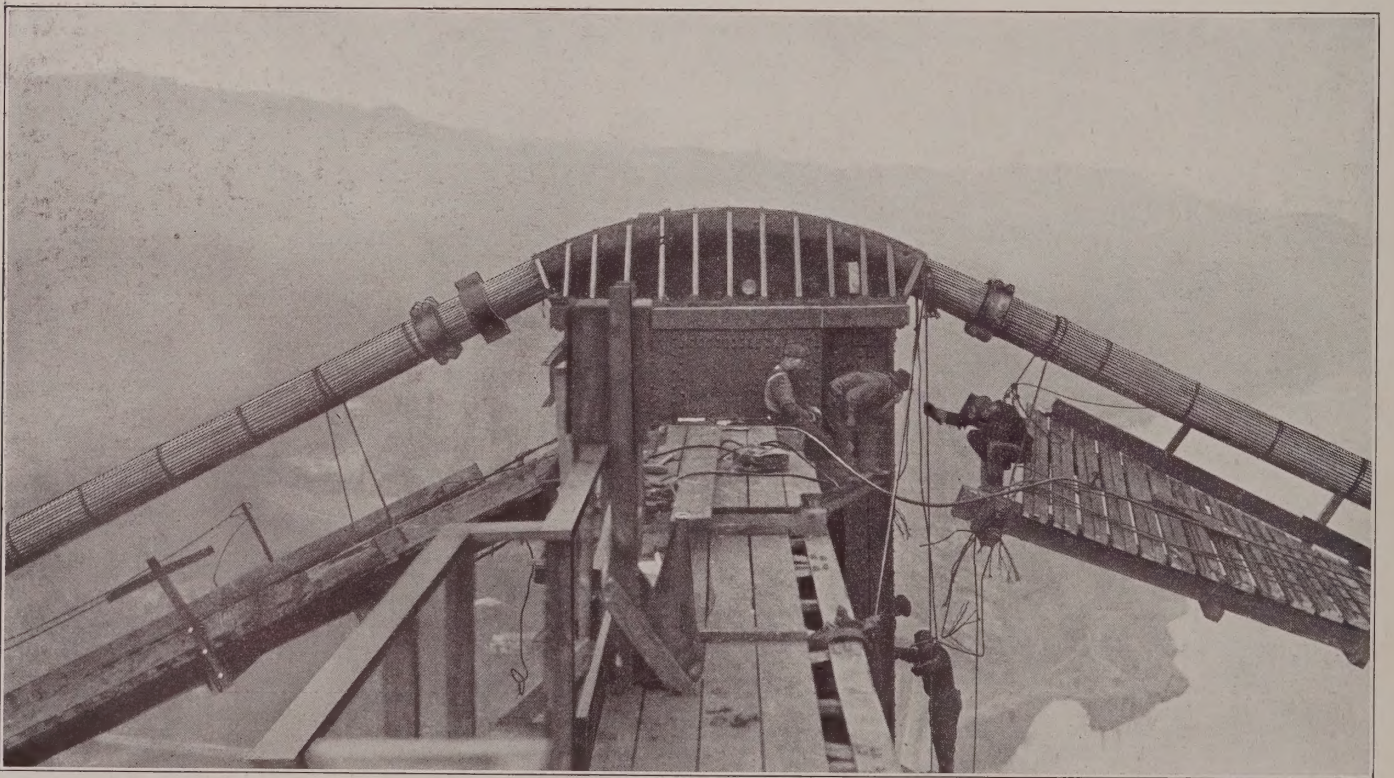


PLATE No. 39—Dismantling the timber platforms and "cleaning up" at the tower tops.

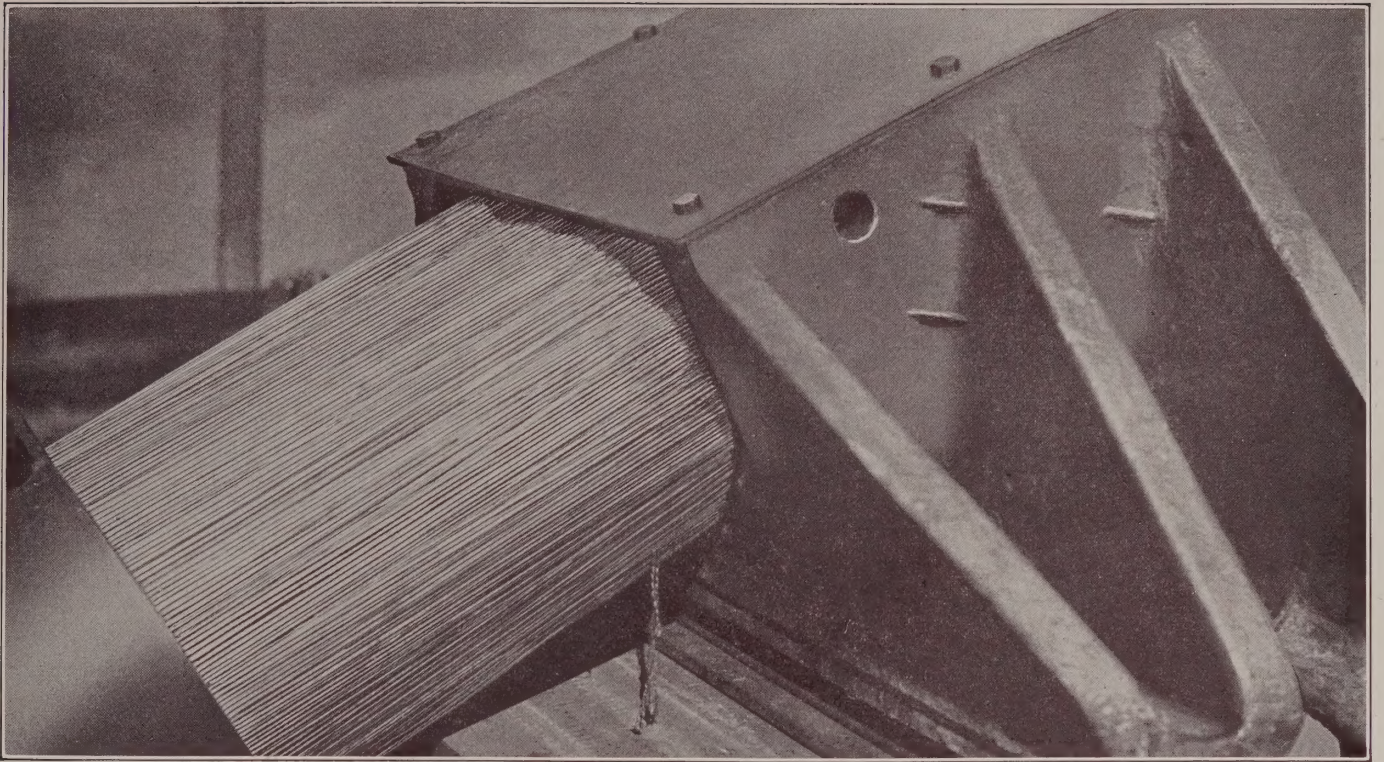


PLATE No. 40—The cable emerging from the steel supporting saddles on the top of the west tower.

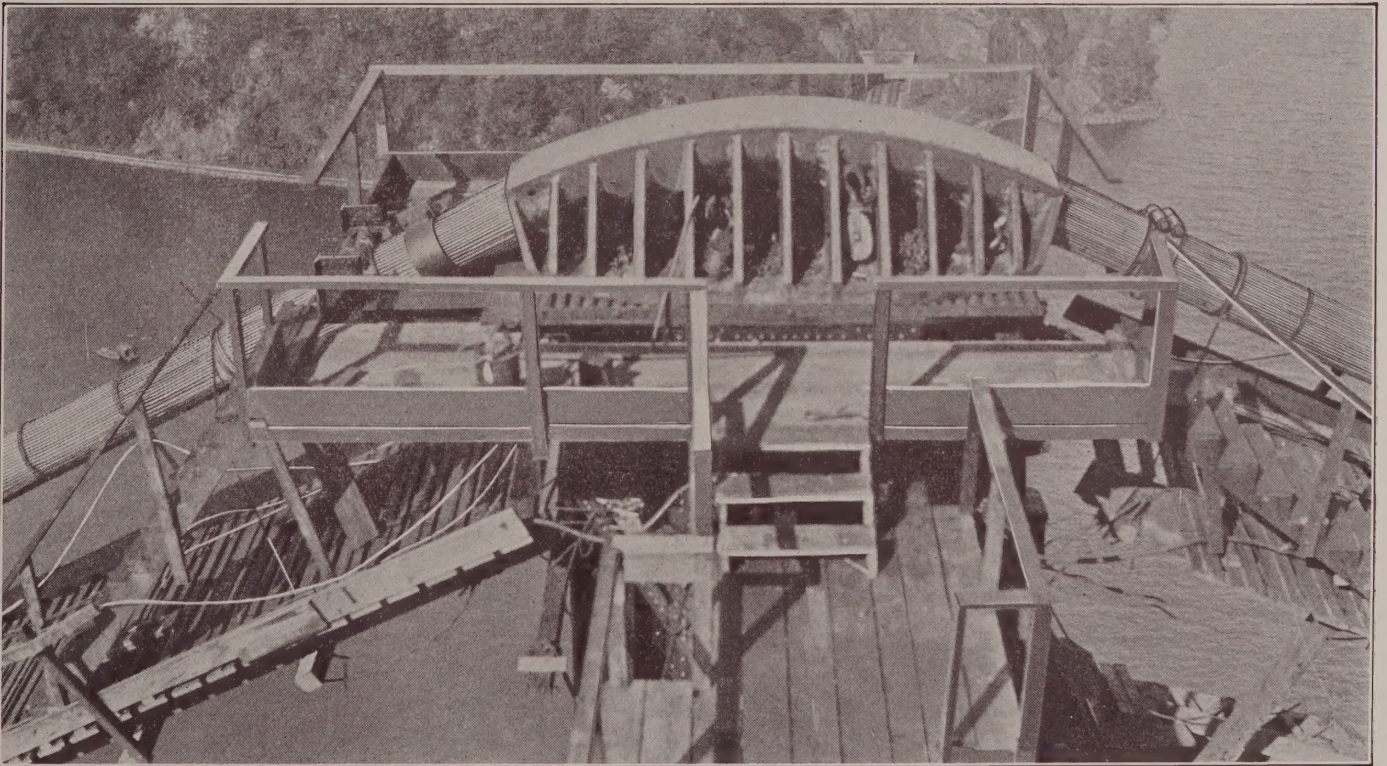


PLATE No. 41—Note the departure of the cables over the supporting saddles. These saddles were supported upon rollers to allow the necessary horizontal displacement of the cable during erection. After completion, these saddles will be rigidly attached to the top of the tower, so that any additional displacement will have to be obtained by the flexure of the tower columns.



PLATE No. 42—After the cables were compacted, it was necessary to transfer the foot bridge loadings direct to the main cables, in order that the foot bridge ropes could be removed and cut into multiple lengths to be used as suspender ropes. To accomplish this, the foot walks were lashed to the main cables in the manner shown above.



PLATE No. 43—Filling in around the eyebar chains with concrete.

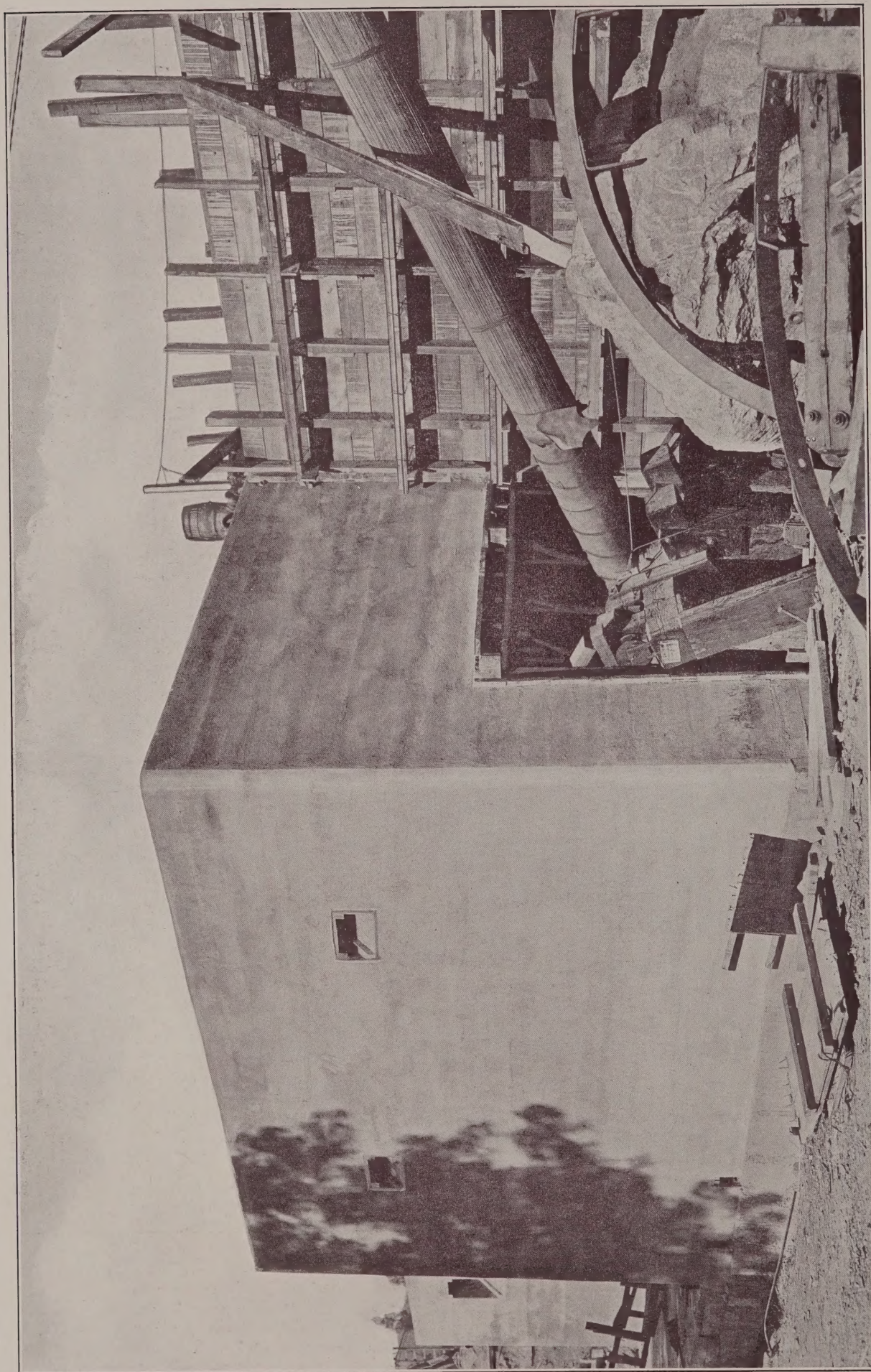


PLATE No. 44—The concrete housing over the west anchorage to protect the wires in the separated strands at their connection to the eyebar chains.

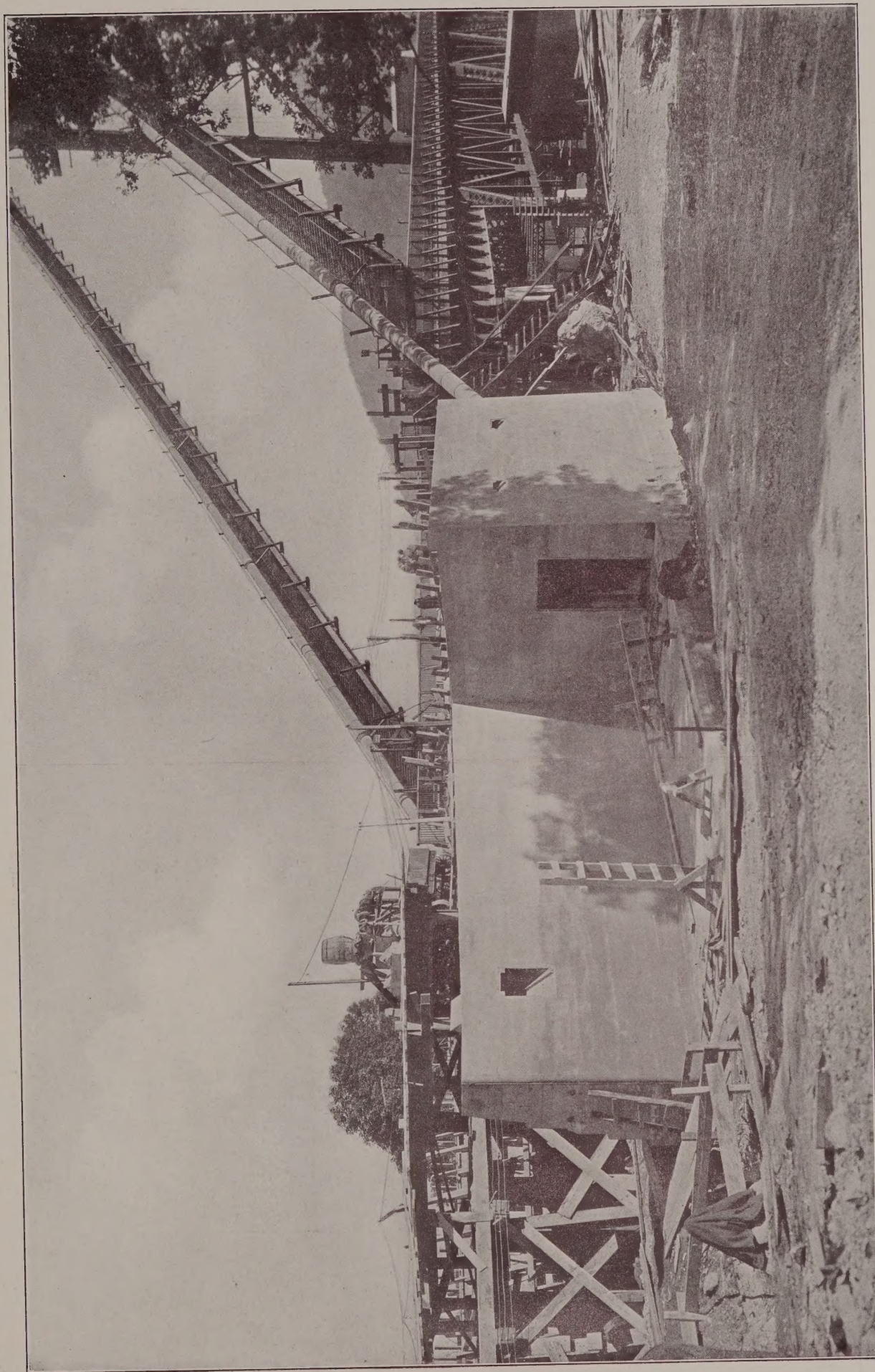


PLATE No. 45—Another view of the west anchorage house. Note the completed cables with foot walks suspended.

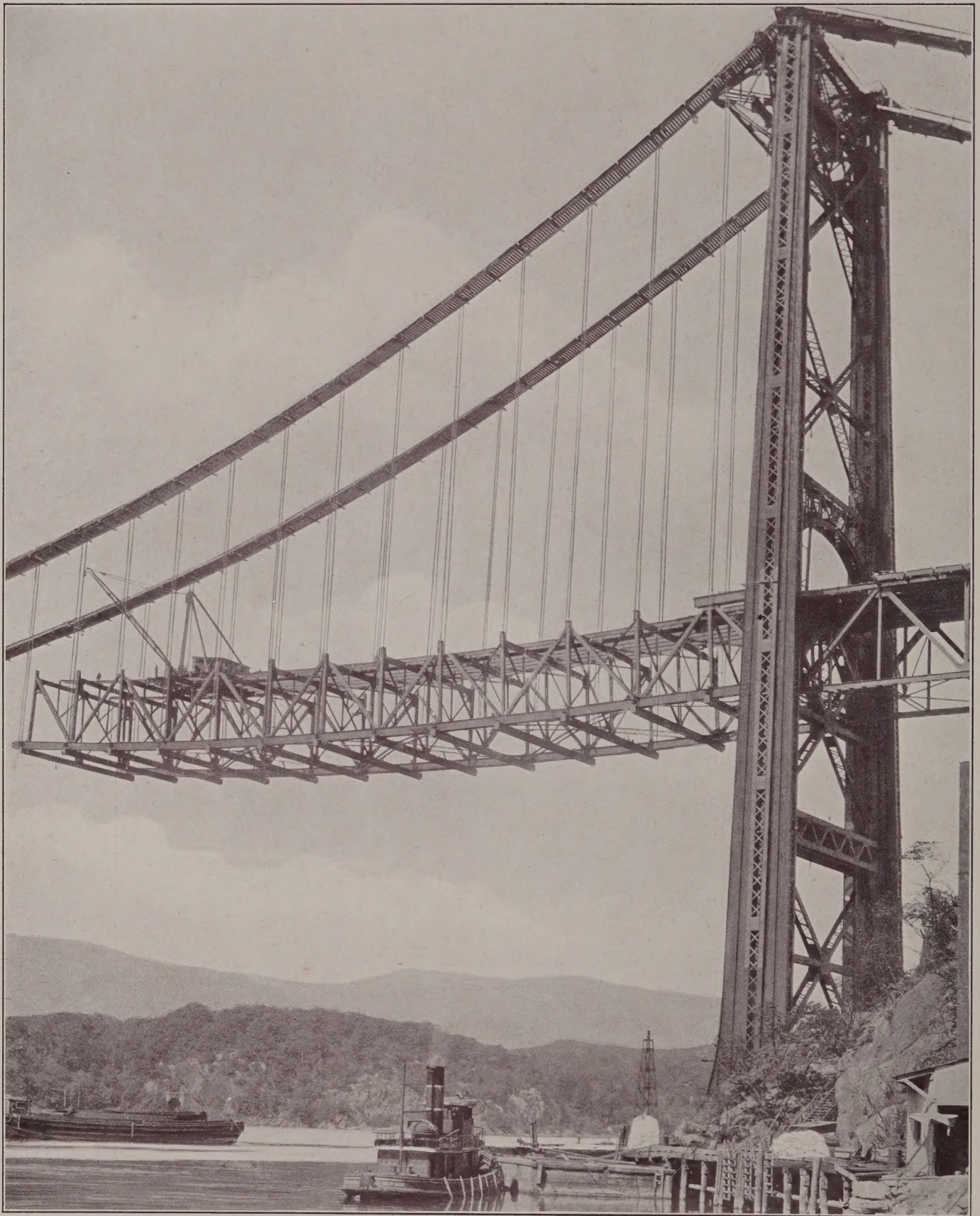


PLATE No. 46—The cables are completed and the erection of the superstructure in progress. The steel truss members are shipped to the bridge site on barges, and the individual members are hoisted to the floor level by means of gasoline-driven derricks. The superstructure is erected simultaneously from both towers, so as to equalize the load on the cable and its resulting reaction upon the towers.

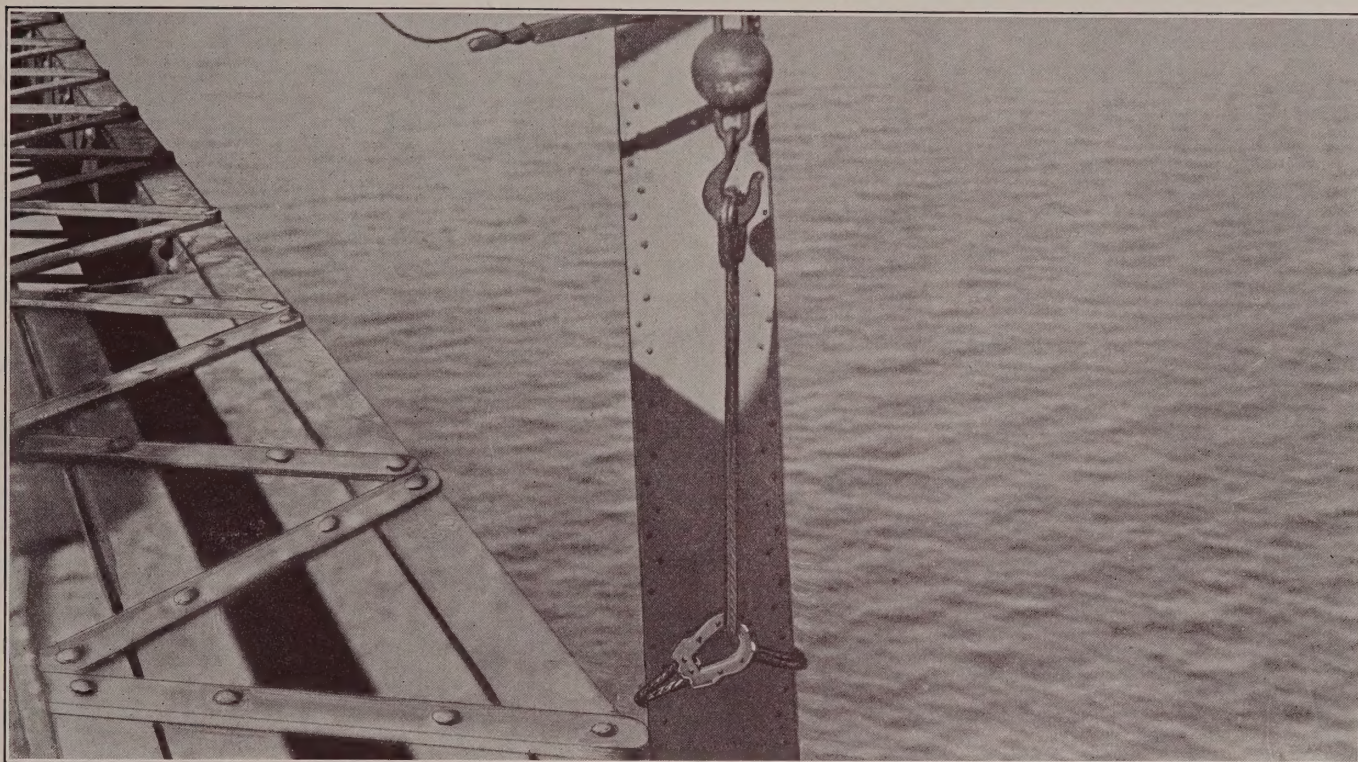


PLATE No. 47—To facilitate the hoisting of these heavy steel members Roebling grommet slings were used.

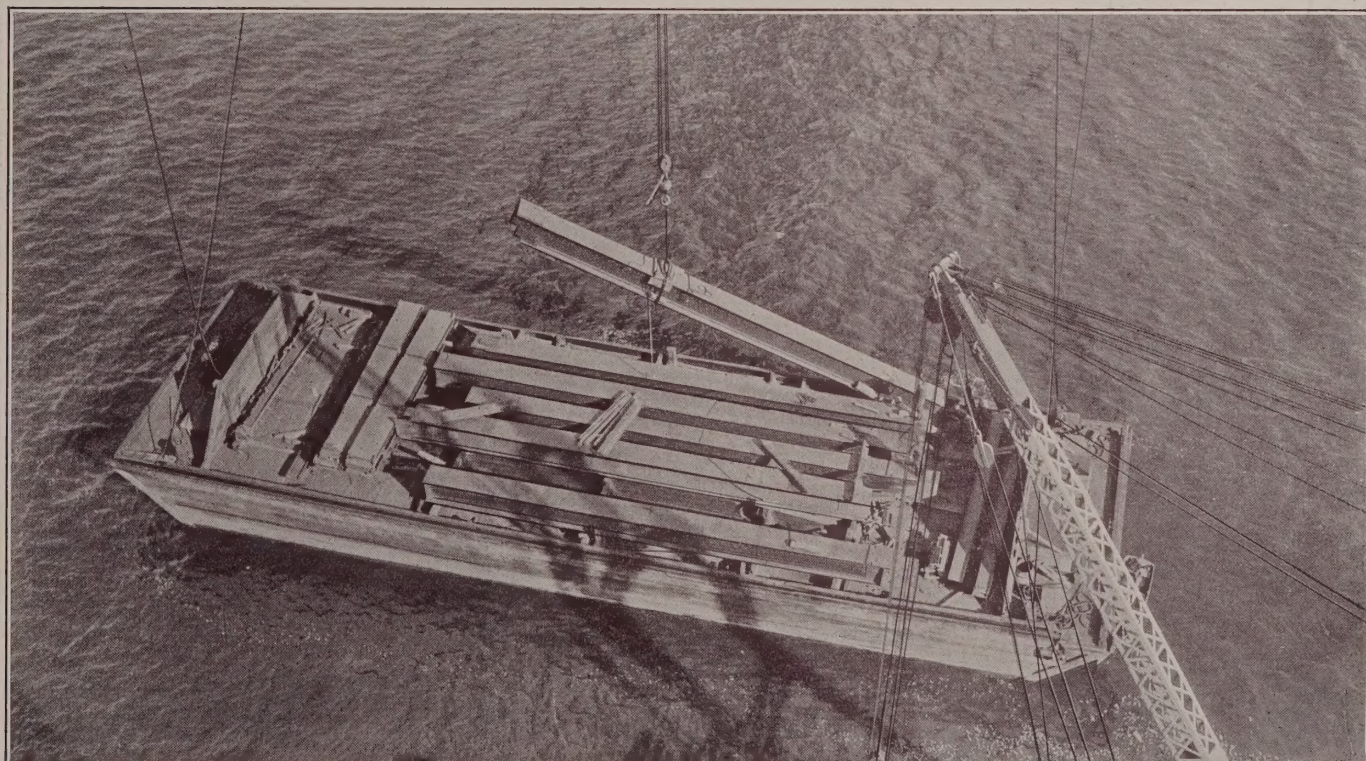


PLATE No. 48—Hoisting a chord member from one of the barges.

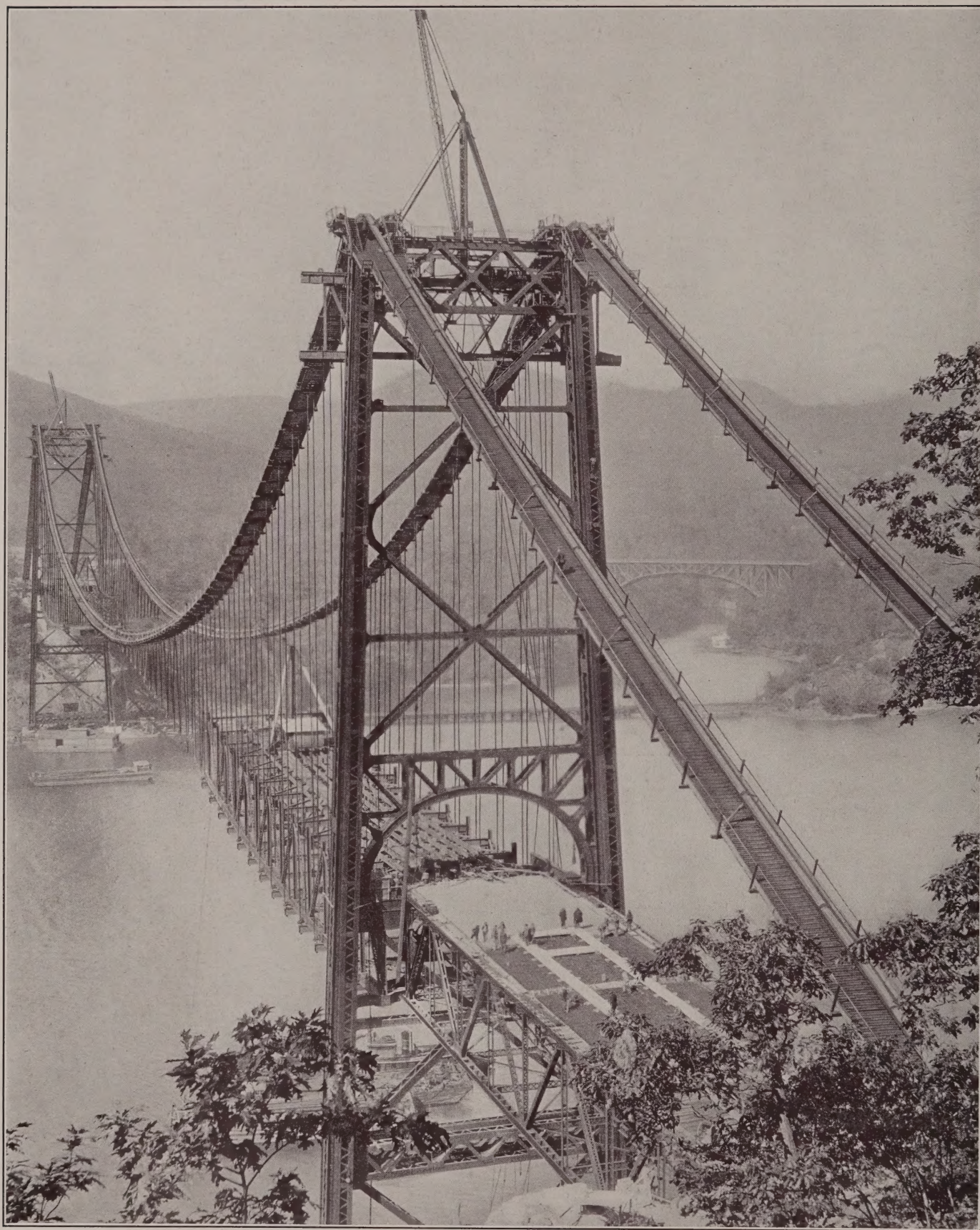


PLATE No. 49—The suspenders are all in place with the truss system advanced about 200 feet from each tower. The work of concreting the roadway upon the east approach span is in progress

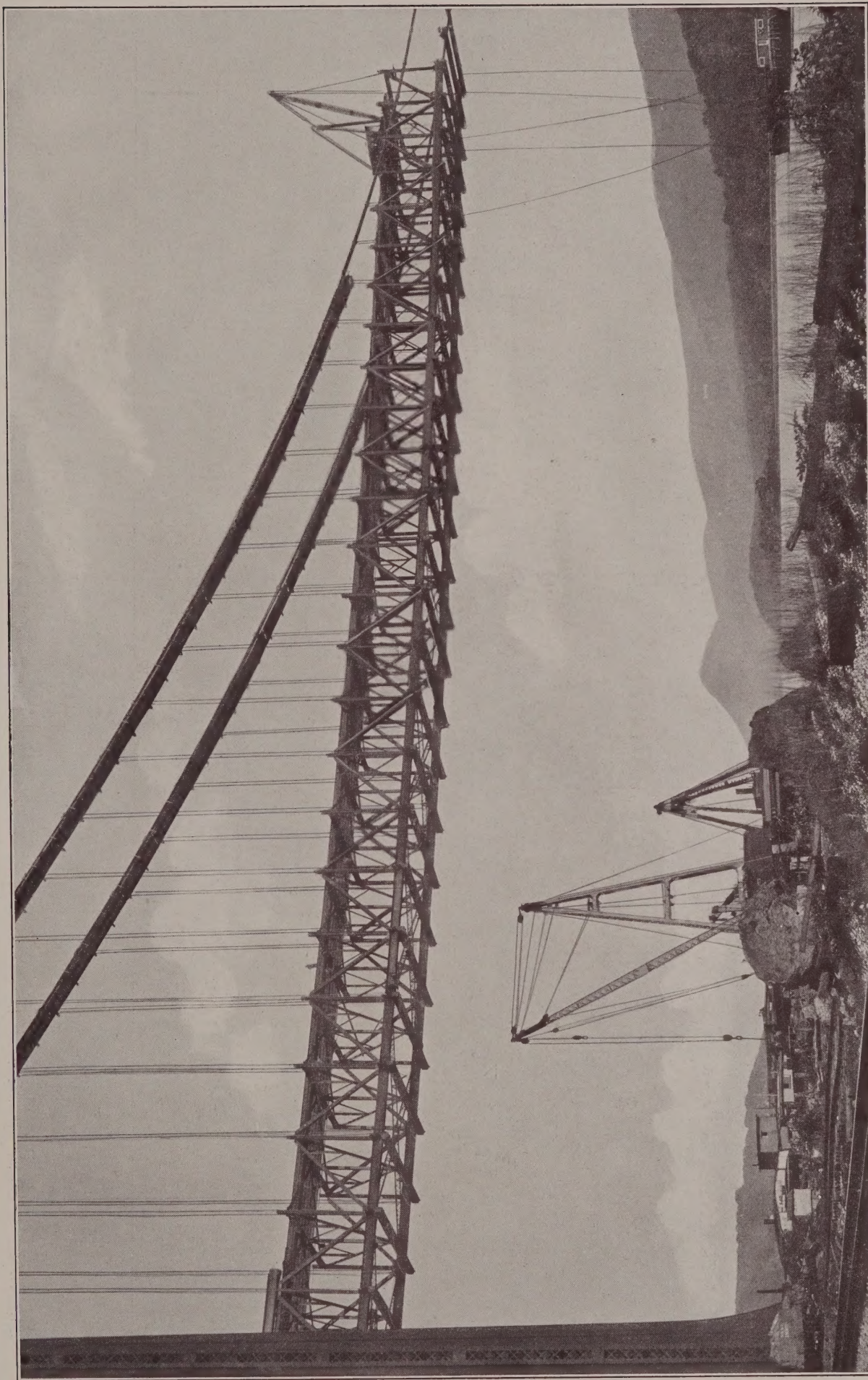


PLATE No. 50.—Section after section has been placed until the superstructure is approaching the junction of the center of the span.



PLATE No. 51—With the placing of the two lower chords a solid steel connection has been made from shore to shore.

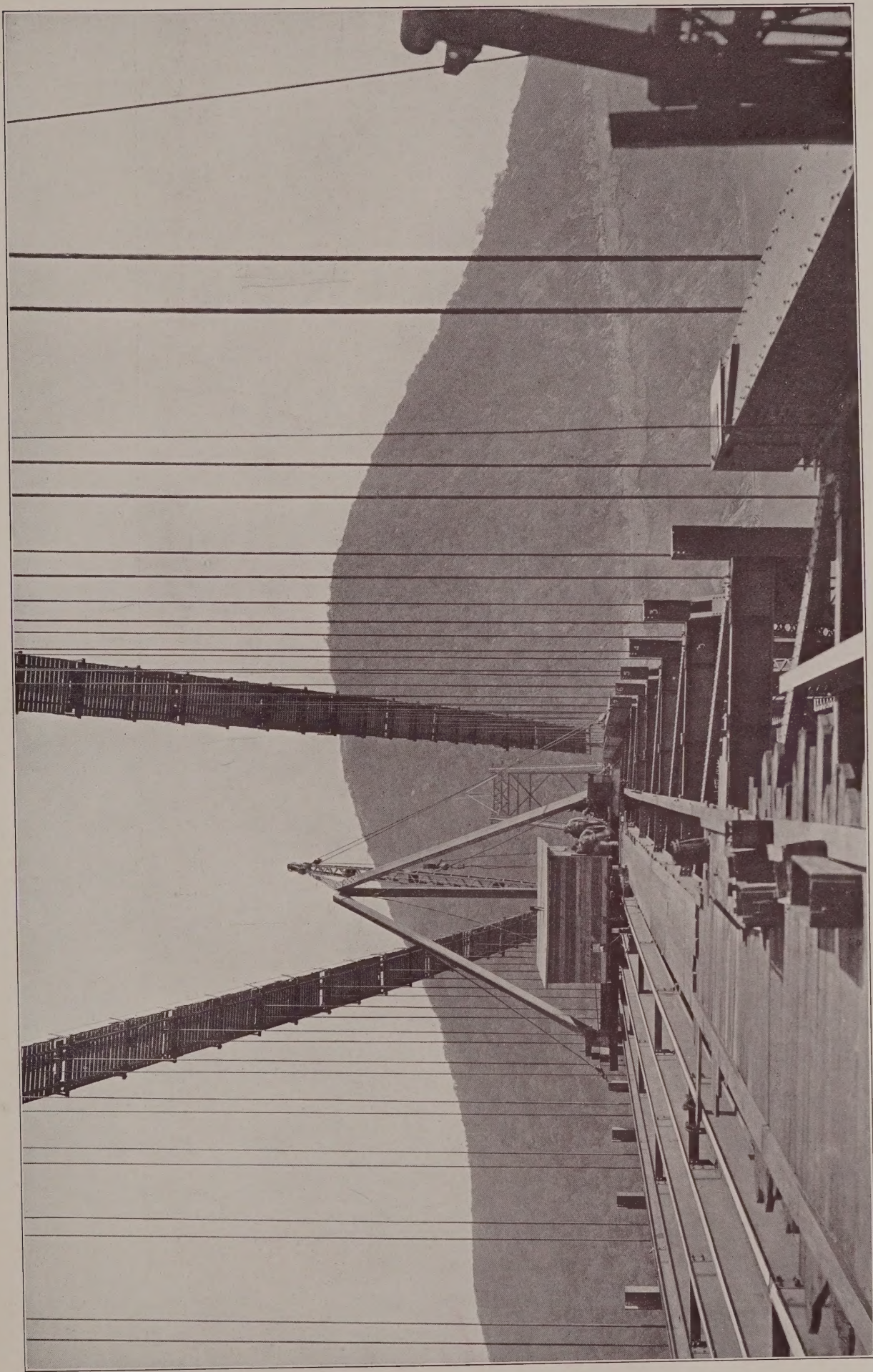


PLATE No. 52—The traveling derricks are shown receding toward the towers placing the upper chords and completing the truss fabrication after having met at the center with the lower chords and connecting members. The superstructure being of deck type, the roadway proper is laid at the level of the top chords which allows an unobstructed view up and down the river.

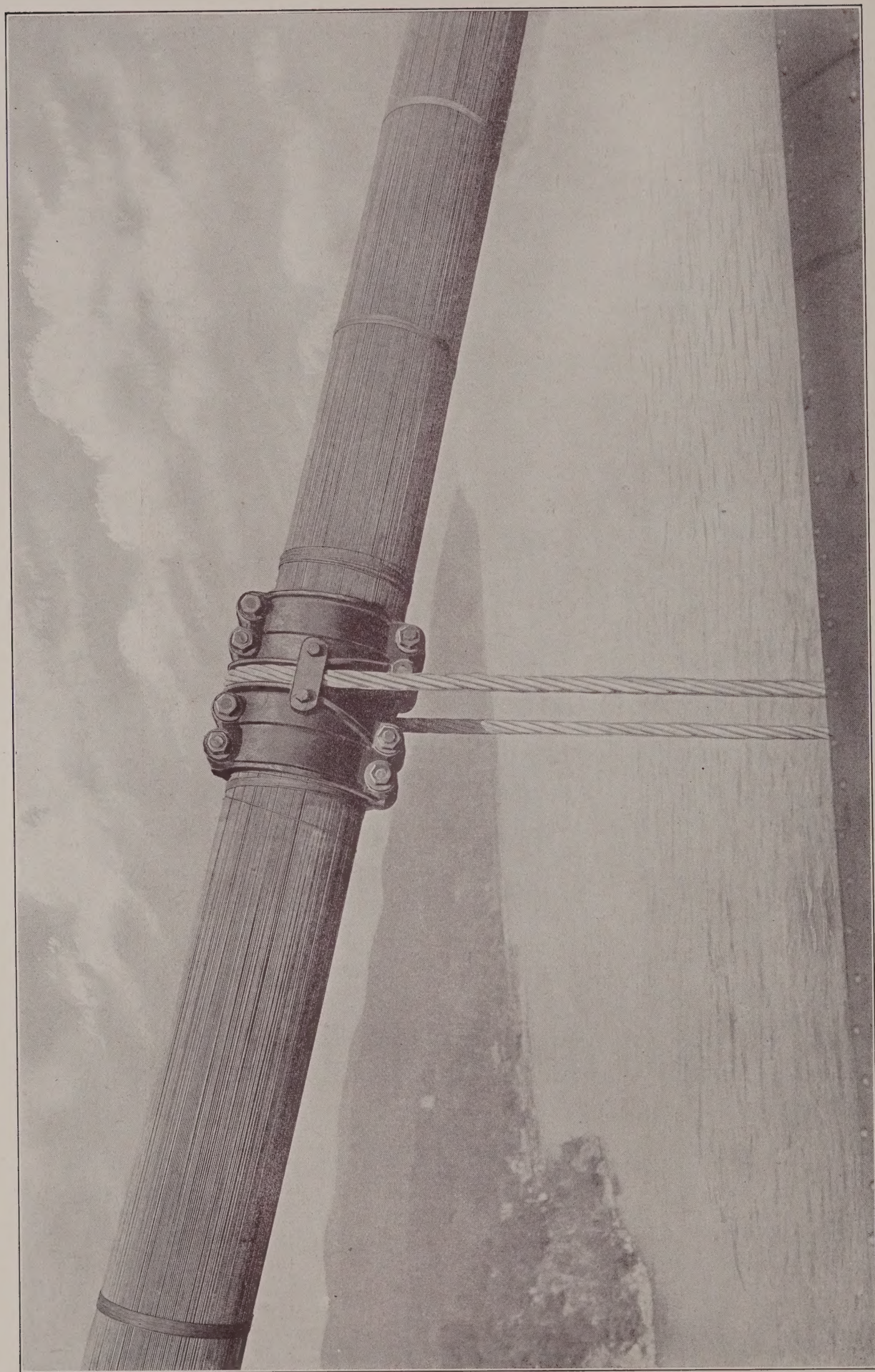


PLATE No. 53—An example of correct cable construction. The parallel relation of the individual wires can be readily observed. There is also shown the steel cable clamp. This clamp forms a saddle for the suspender ropes which in turn support the entire weight of the suspended span. The suspenders are $2\frac{1}{4}$ -inch diameter galvanized steel rope composed of seven strands of 19 wires each, having an ultimate strength of approximately 210 tons.

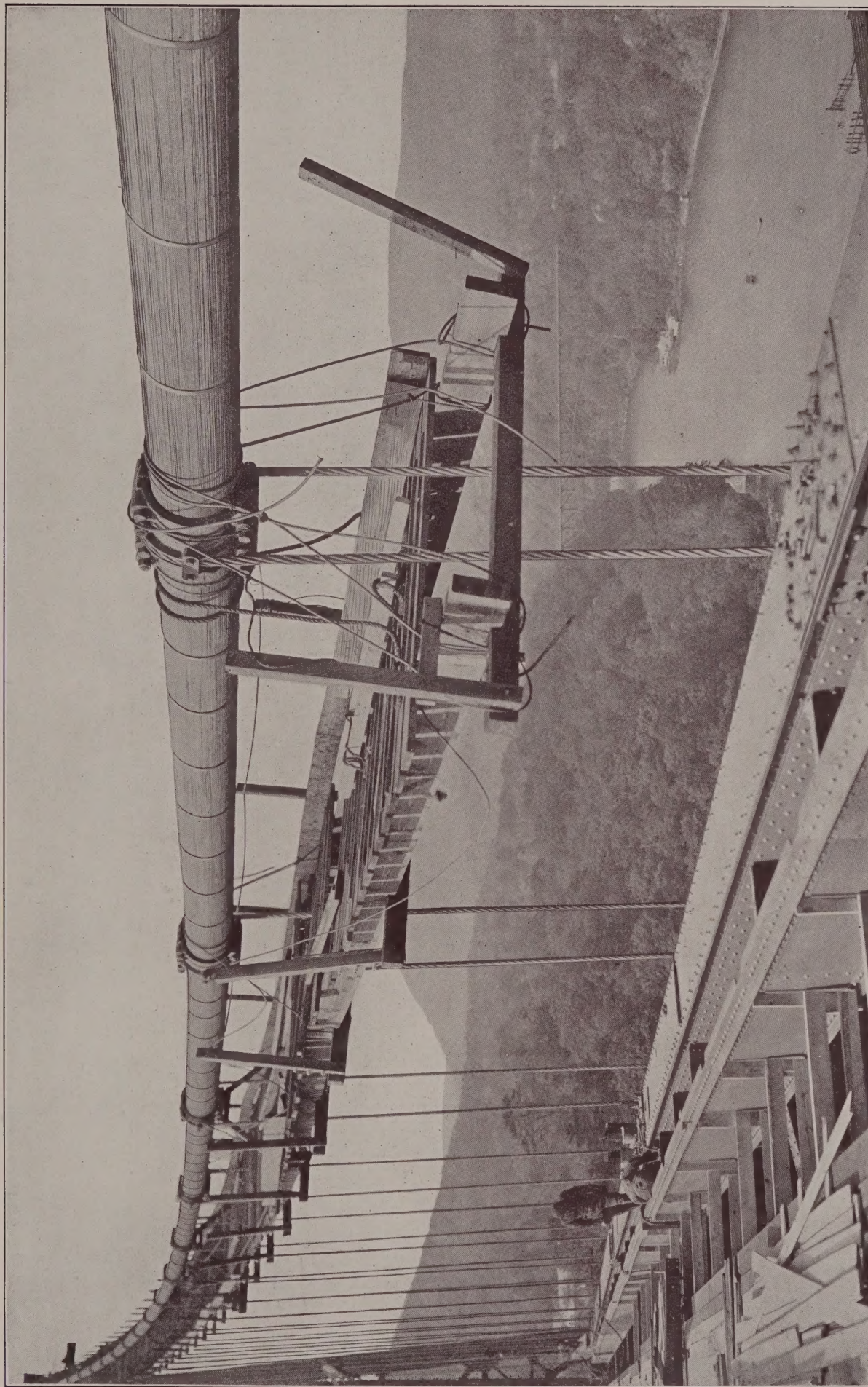


PLATE No. 54—It was necessary to remove a section of the foot walks near the center of span to allow for the erection of the trusses. The method of lashing the walks to the main cables can be clearly seen above. A portion of one of the chord splices can be seen in the foreground.

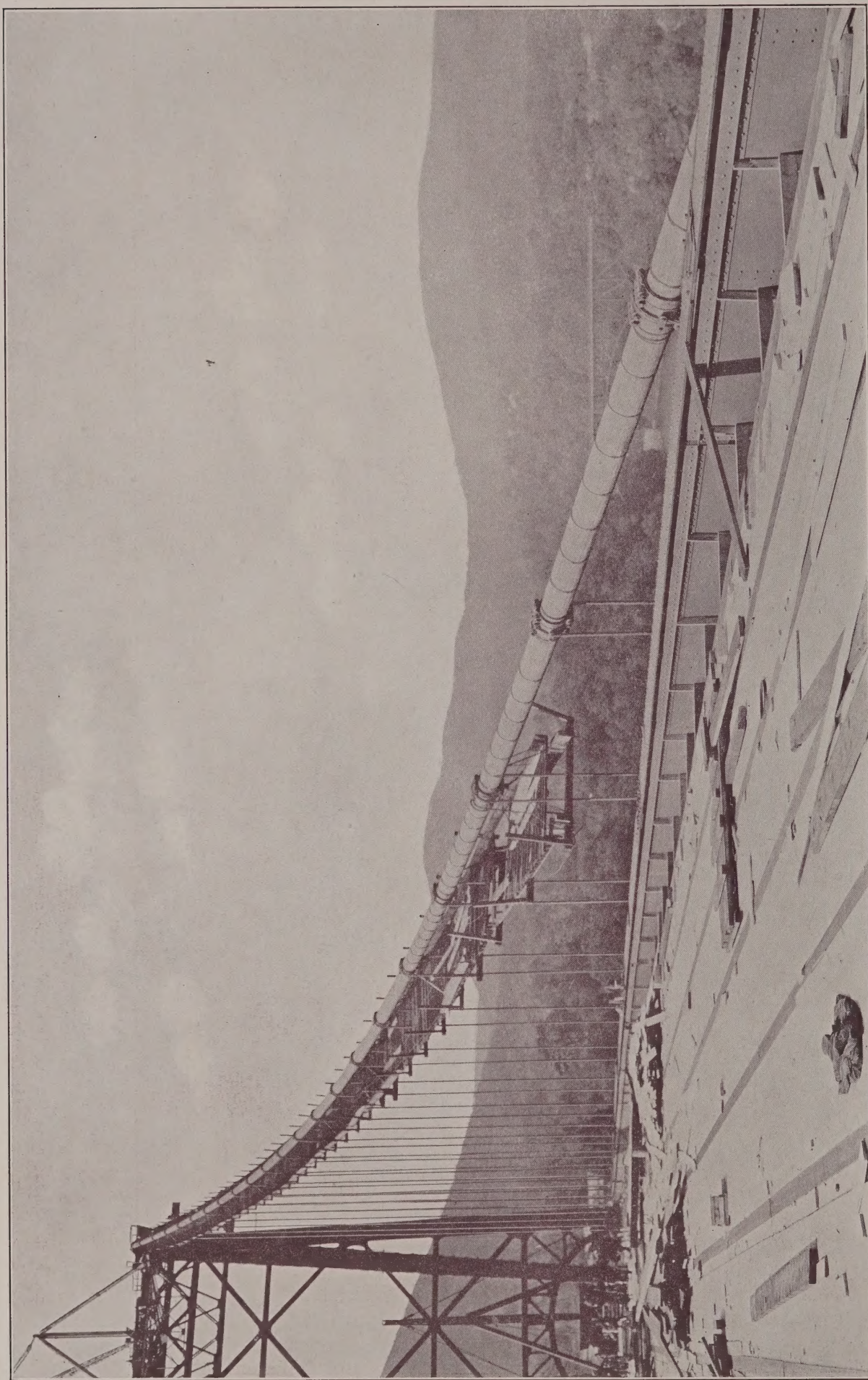


PLATE No. 55—Placing the forms for the reinforced concrete roadway. The steel floor stringers can be seen paralleling the roadway.

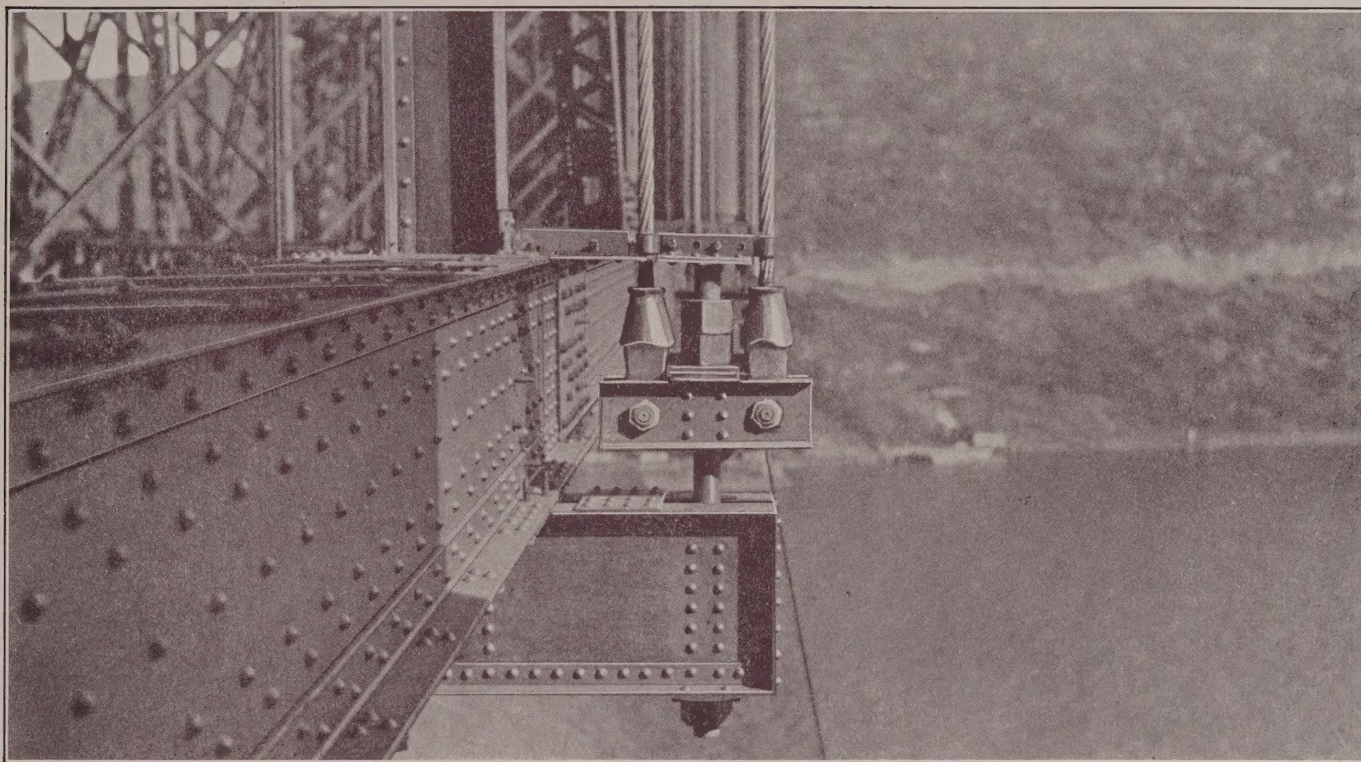


PLATE No. 56—In order to equalize the stress in both parts of the suspender ropes, they are attached to an equalizer beam from which the transverse floor beams of the superstructure are suspended by means of a single bolt. This bolt also allows adjustment of the suspender lengths during erection.

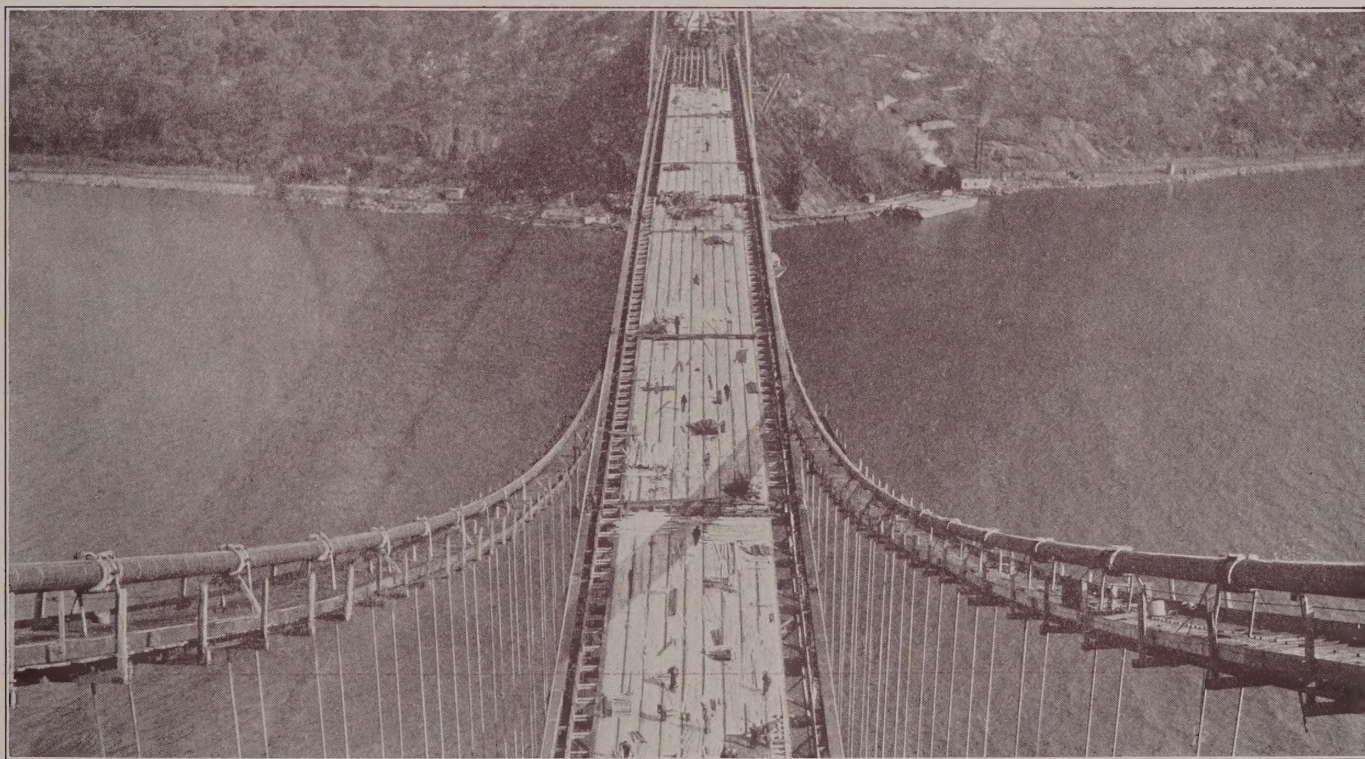


PLATE No. 57—Looking east from the top of the west tower, showing the completed truss system and the placing of forms for the roadway.



PLATE No. 58—Metal reinforcement for the roadway in place, and runway set ready for the pouring of the concrete.

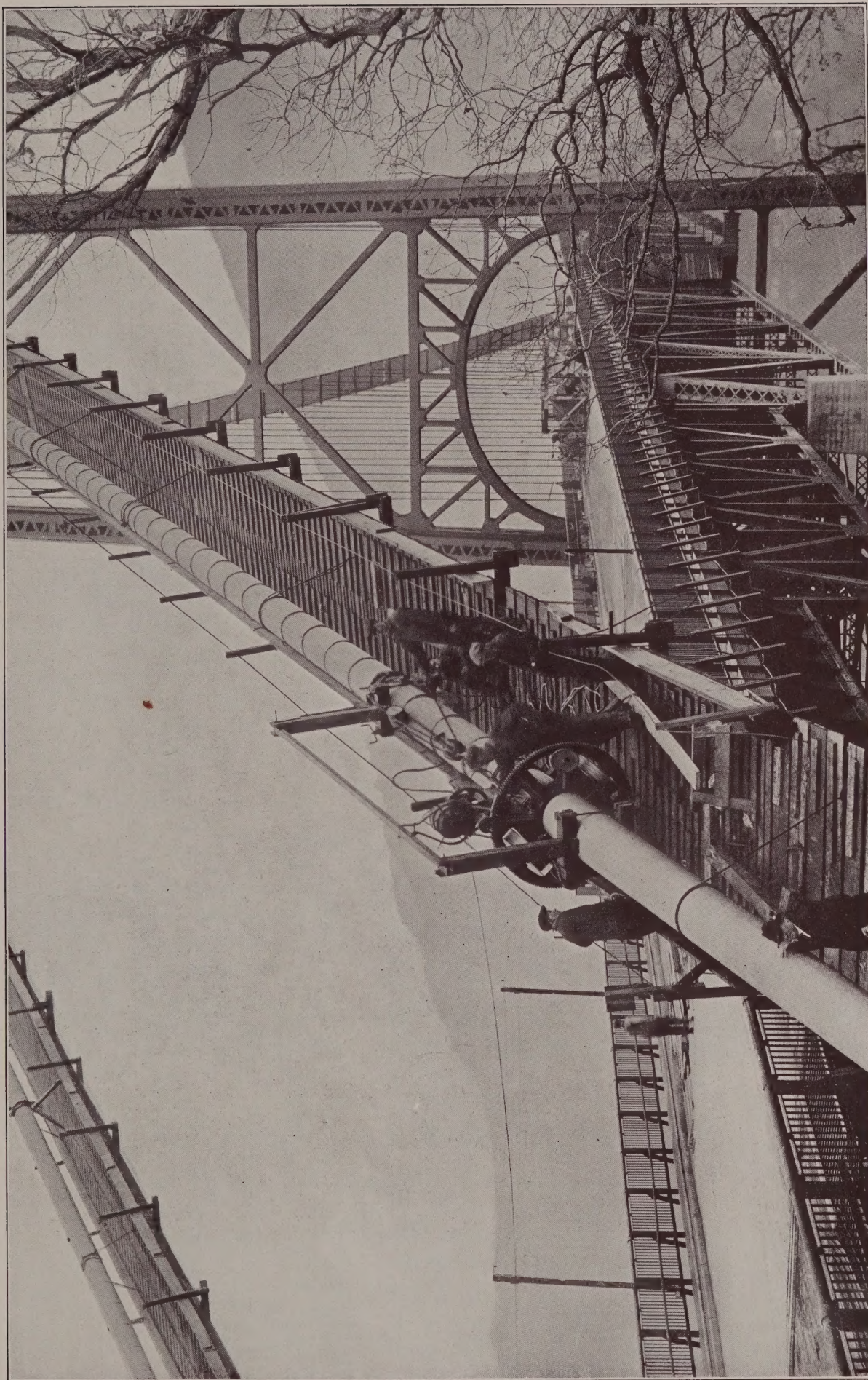


PLATE No. 59—In order to protect the cables from the action of the elements, they are first thoroughly painted with red lead. They are then covered with a continuous wrapping of soft annealed galvanized wire 0.151" in diameter over which is later placed a protective coating of waterproof paint. This wire wrapping is served by means of an electrically driven 2-bobbin machine, as shown above.

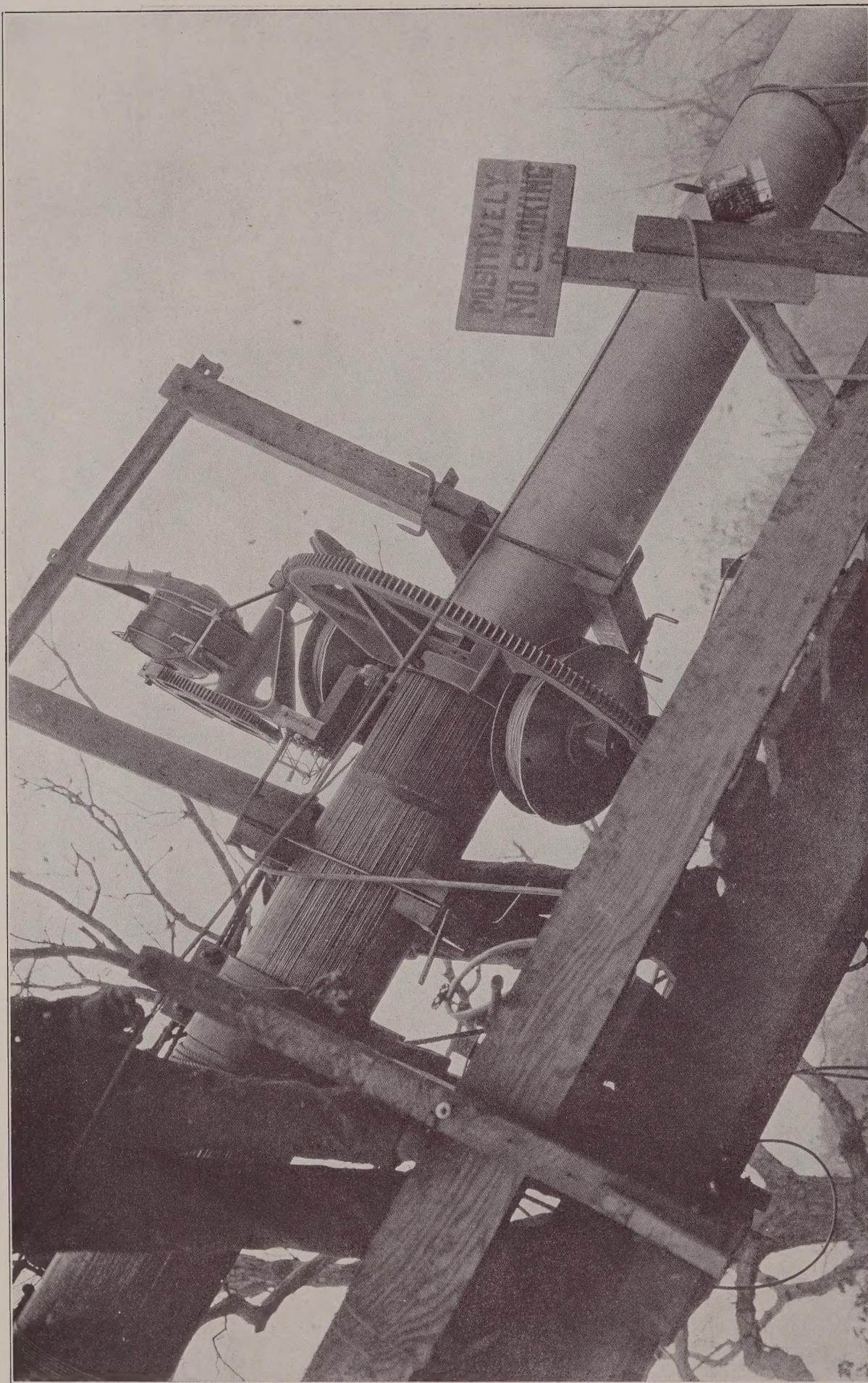


PLATE No. 60—The above photograph clearly shows the detail of the cable-wrapping machine. This machine is propelled up the slope by friction of each additional wrap against the ones previously laid. The frame wheel revolves free from the cable, having a sliding bearing upon a plate which slides on top of the cable and which also forms part of the bracket upon which the electric motor is mounted.

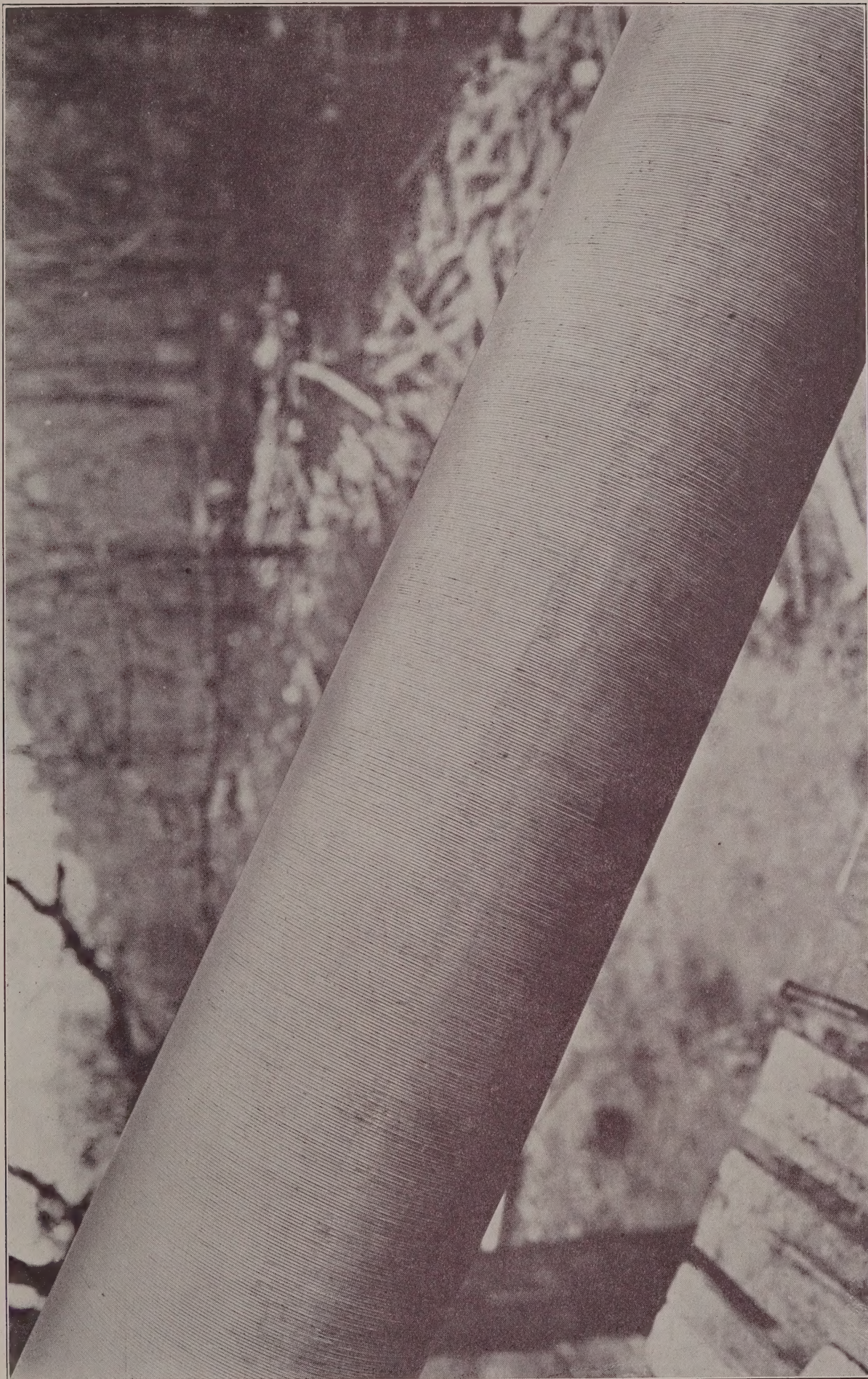


PLATE No. 61—The section of the finished cable with wrapping applied.



PLATE No. 62—After the completion of the super-structure, with the total weight of finished roadway suspended from the cables, the tower saddles were rigidly bolted to the tower tops, the rollers burned off even with the sides of the saddle, and, in order to prevent possible rotation, were frozen fast by the use of metal cement.

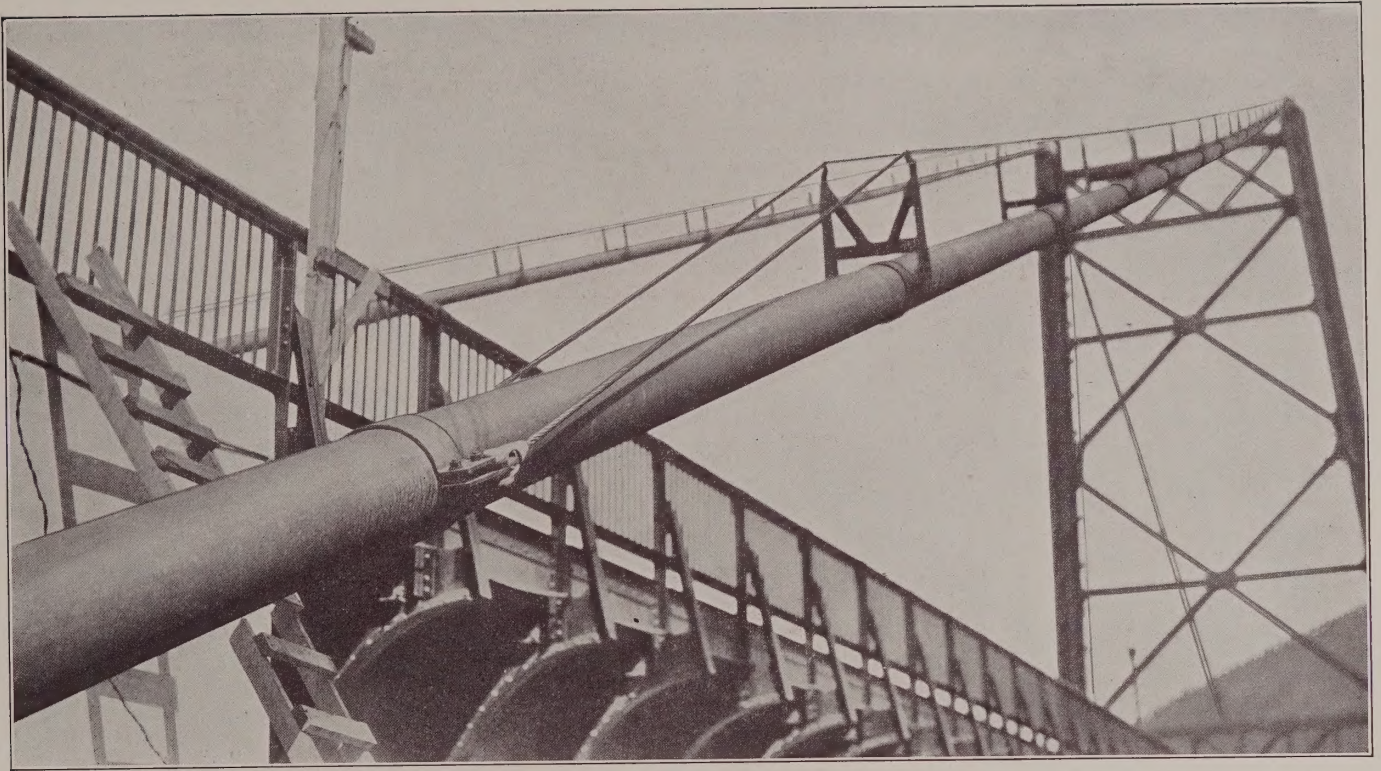


*PLATE No. 63—Hand rail ropes on back-stay of
land span of cable.*

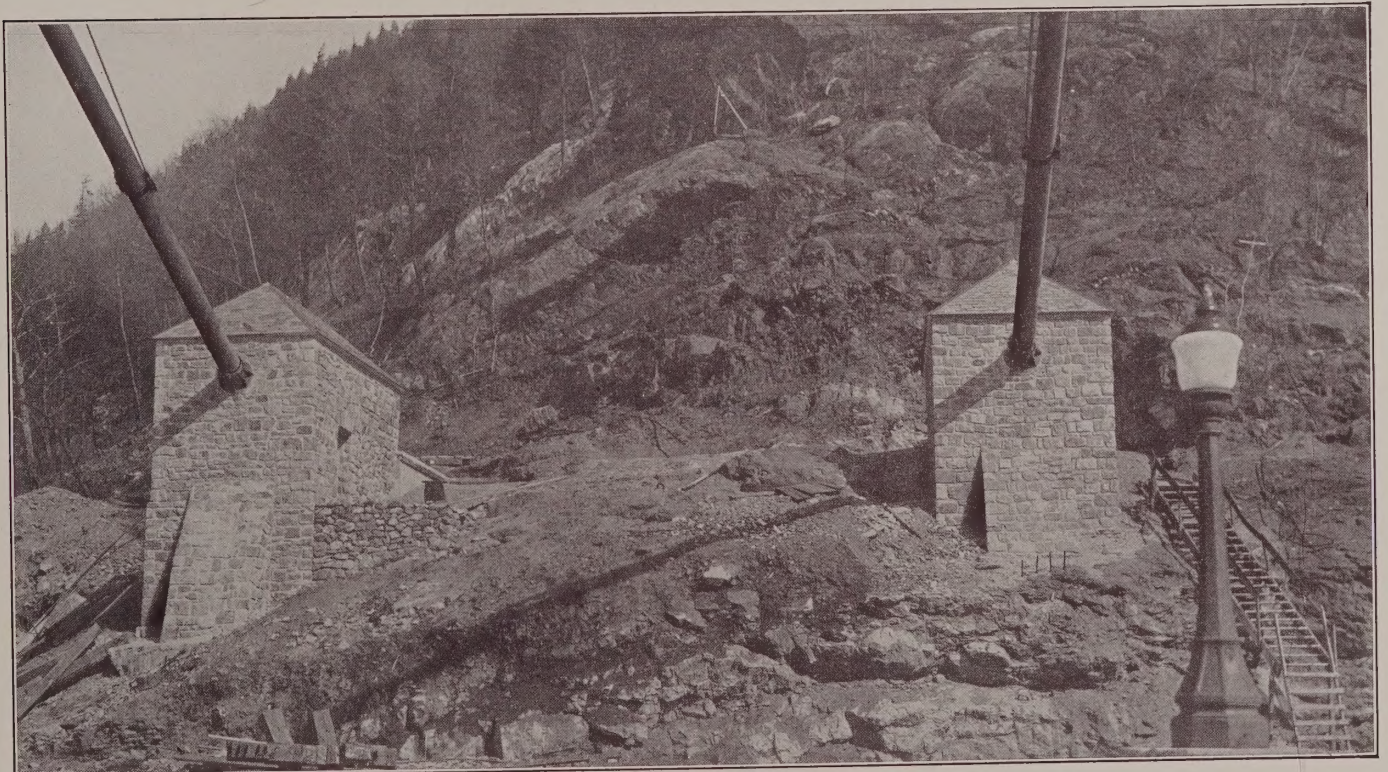


*PLATE No. 64—Anchorage housings at eastern
end of cables.*

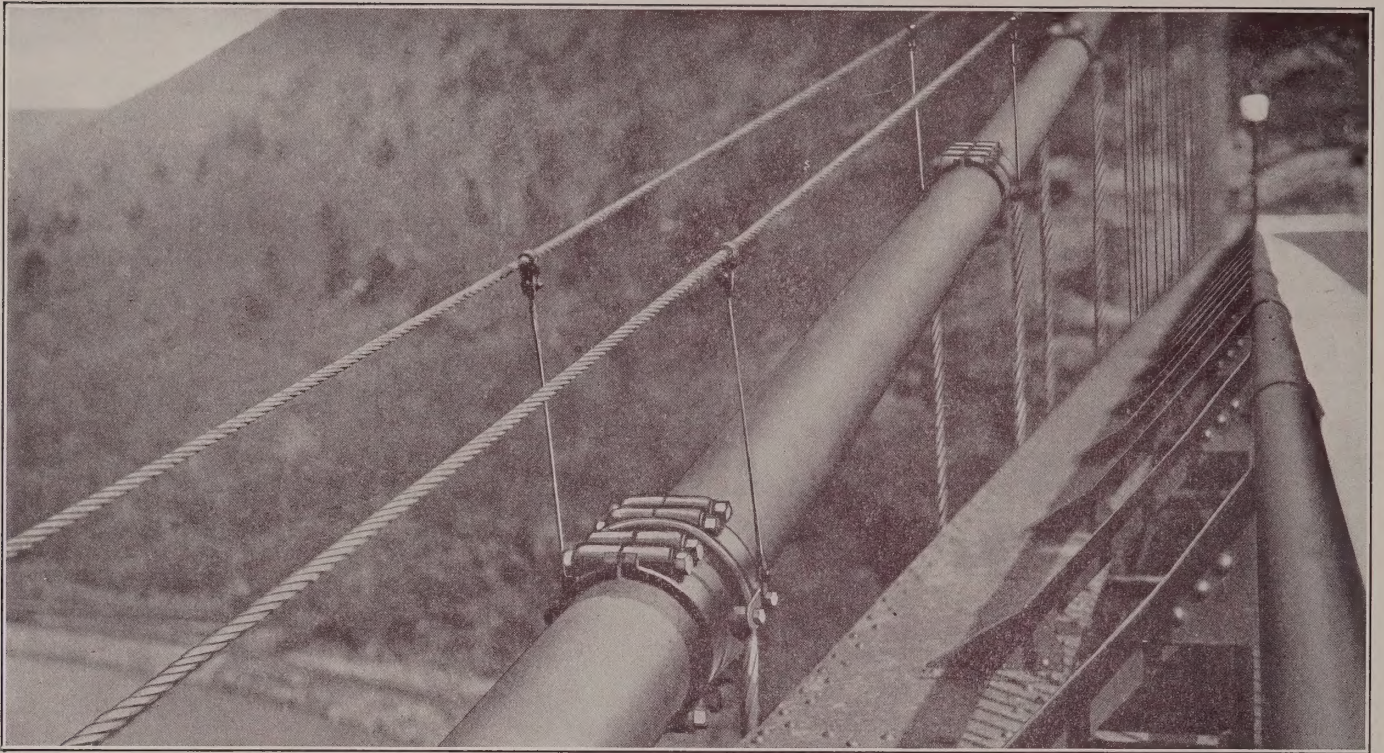


*PLATE No. 65—Hand rail ropes on main span
of completed cable.*

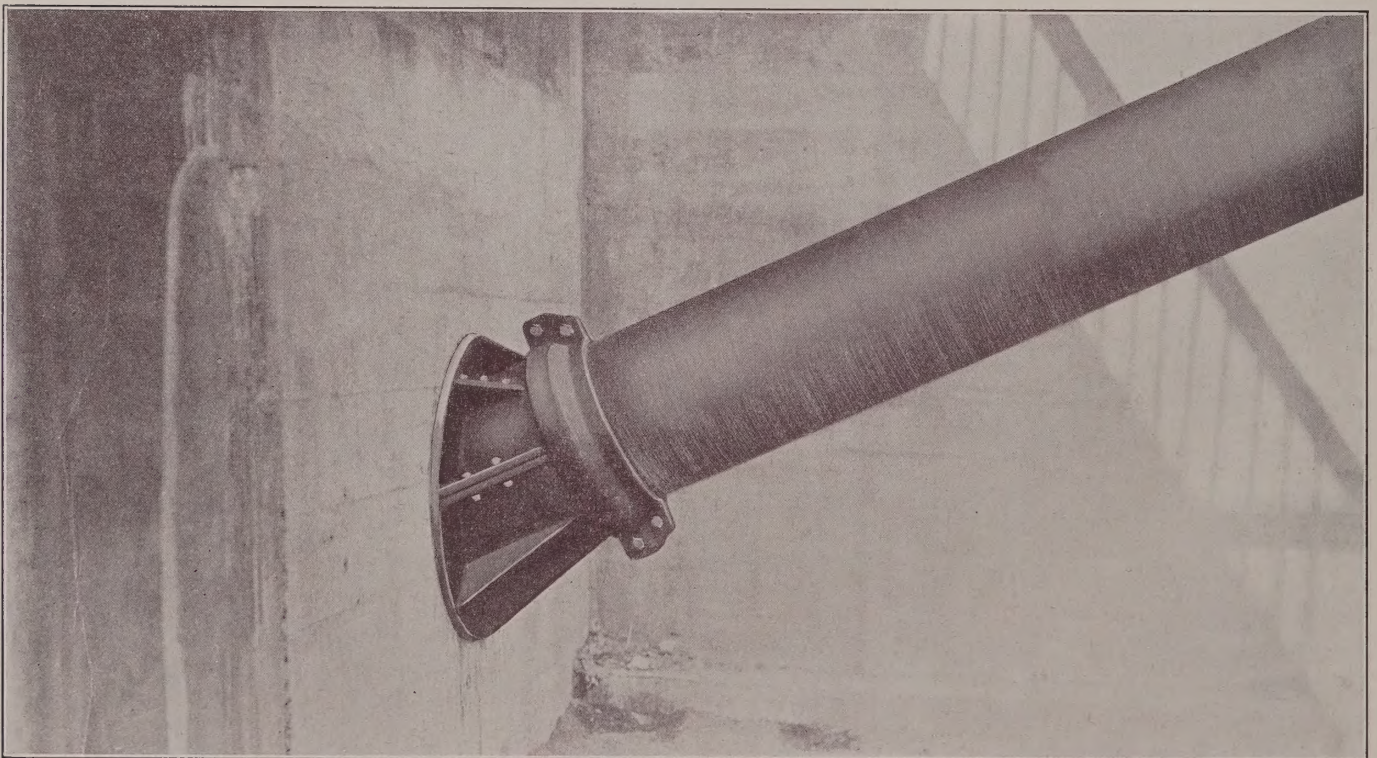
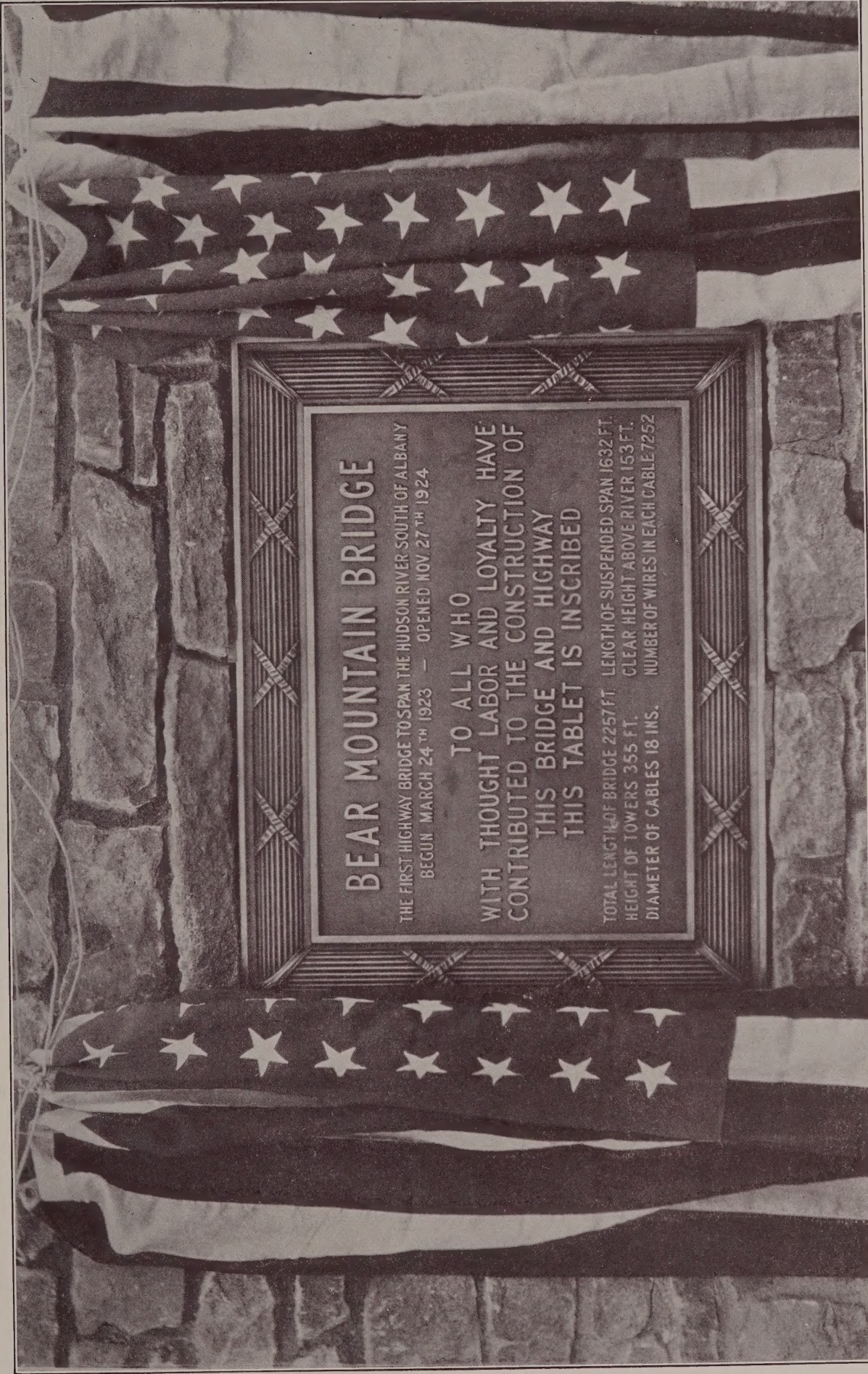


*PLATE No. 66—The waterproof collar on the
cable outside of the anchorage housing.*



BEAR MOUNTAIN BRIDGE

THE FIRST HIGHWAY BRIDGE TO SPAN THE HUDSON RIVER SOUTH OF ALBANY
BEGUN MARCH 24TH 1923 — OPENED NOV. 27TH 1924

TO ALL WHO
WITH THOUGHT, LABOR AND LOYALTY HAVE
CONTRIBUTED TO THE CONSTRUCTION OF
THIS BRIDGE AND HIGHWAY
THIS TABLET IS INSCRIBED

TOTAL LENGTH OF BRIDGE 2257 FT. LENGTH OF SUSPENDED SPAN 1632 FT.
HEIGHT OF TOWERS 355 FT. CLEAR HEIGHT ABOVE RIVER 153 FT.
DIAMETER OF CABLES 18 INS. NUMBER OF WIRES IN EACH CABLE 7252

PLATE No. 67—The sentiment expressed upon this tablet is indeed fitting,
for the highest praise is deserved by all who made this structure possible.

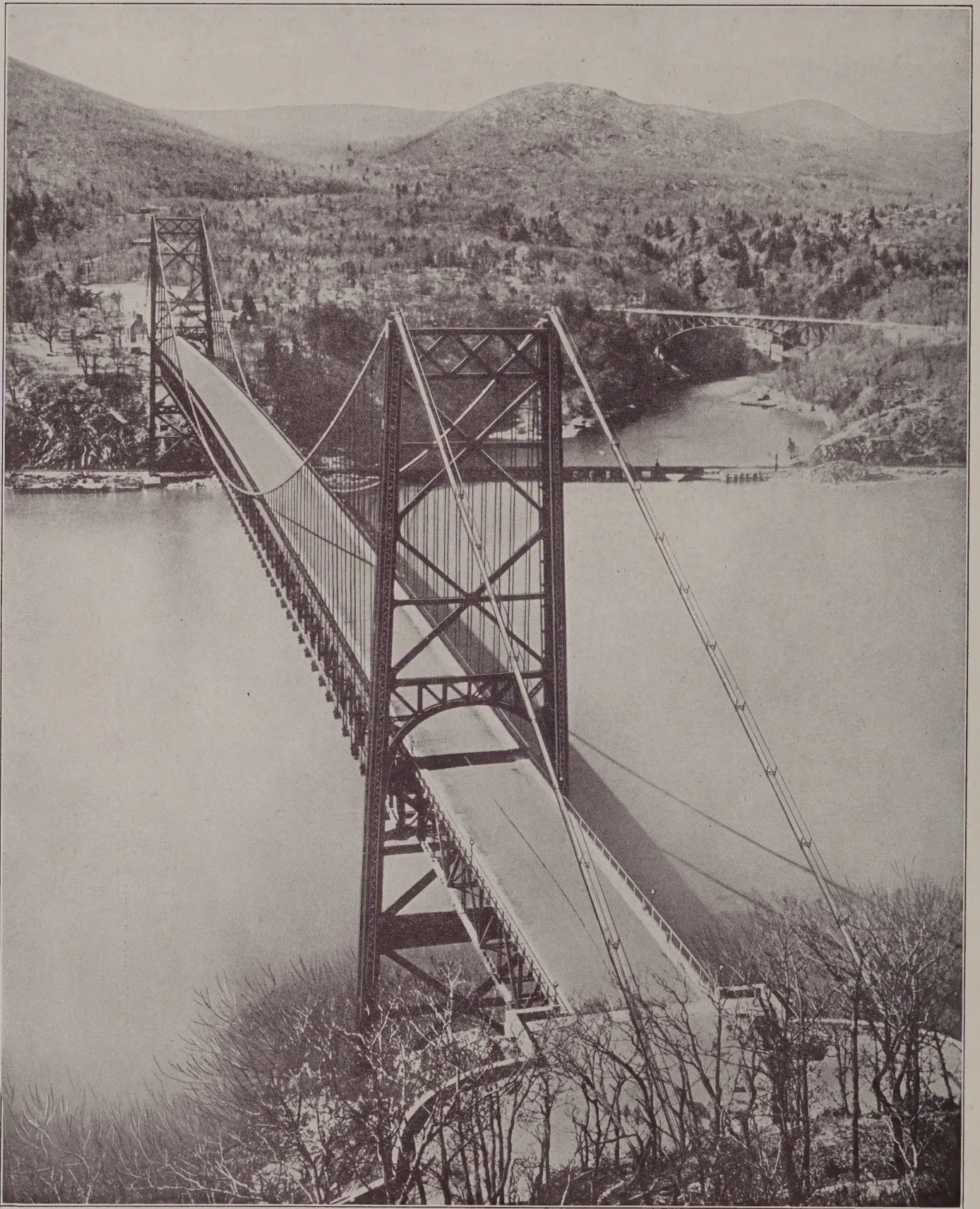


*PLATE No. 68—The finished bridge
open to traffic.*

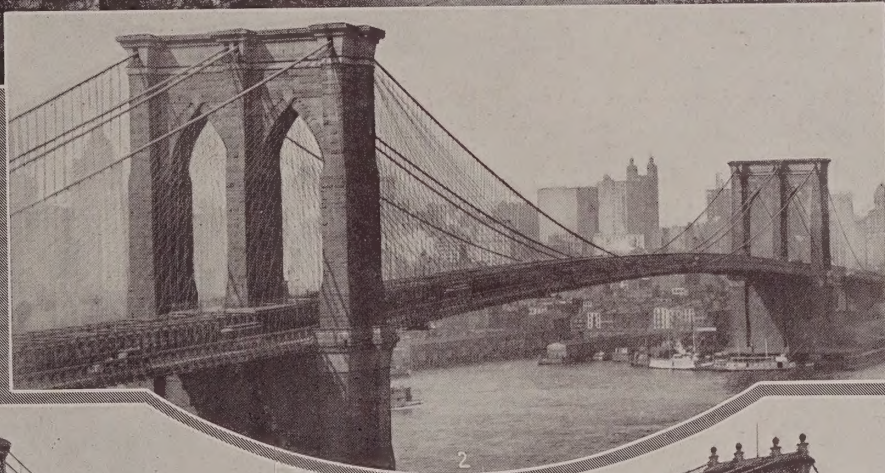
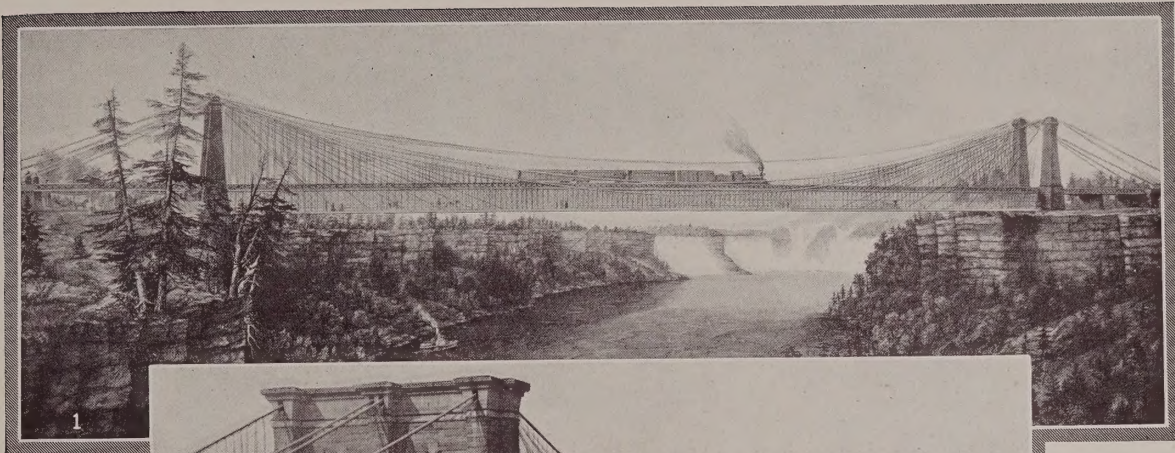


PLATE No. 69—1.—Niagara Falls Bridge (1854).
 2.—Brooklyn Bridge (1883).
 3.—Williamsburg Bridge (1903).
 4.—Manhattan Bridge (1909).
 5.—Bear Mountain Bridge (1924).

ERRATA

Plate No. 11

Strands No. 1 and No. 4 are spun from East to West, and strands No. 2 and No. 3 from West to East, instead of the reverse as noted at the bottom of this plate.

The third sentence at the bottom of this plate should read: "The tramway is operated by an endless traction rope with a traveling sheave attached at each end of the bridge, ---."

Plate No. 53.

The 2 1/4" diameter suspenders are not of 7x19 construction, but are 6x37 galvanized steel ropes having 7x19 independent wire rope centers.

